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TRANSACTIONS

OF

The Canadian Society of Civil Engineers

VOL. III.

JANUARY TO DECEMBER

1889.

Montreal:
PRINTED FOR THE SOCIETY,
BY JOHN LOVELL & SON.

1890.

The right of publication and translation is reserved.

1896, March 16.
Scientific School.

JUN 20 1917
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Samuel Keefer

PRESIDENT CAN. SOC. C. E.

1888.

PRESIDENT CAN. SOC. C. E.

1888.

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Canadian Society of Civil Engineers.

SESSION, 1889.

TRANSACTIONS.

Thursday, 3rd January.

SAMUEL KEEFER, President, in the Chair.

The following candidates having been balloted for were declared duly elected as

HONORARY MEMBERS.

THE RIGHT HON. LORD STANLEY OF PRESTON, G. C. B., P. C., &c.
SIR JOHN WILLIAM DAWSON, C. M. G., M. A., L. L. D., F. R. S..

MEMBER.

JOHN ST. VINCENT CADDY.

ASSOCIATES.

JAMES COOPER, WILLIAM HENRY HUTTON,
JOHN ROBERT COWANS, JOHN HENRY R. MOLSON,
WALTER TOWNSEND.

STUDENTS.

THOMAS ROBERT HENDERSON, HARFORD KENNETH MOBERLY,
JOHN ERNEST MAY, ORRIN REXFORD,
THOMAS TREMBLAY.

The following has been transferred from the class of Students to that of Associate Members,

FRANCIS W. W. DOANE.

Paper No. 26.

THE PANAMA CANAL.

By E. DENIEL, M.CAN.SOC.C.E.

Twenty years hardly had elapsed since the discovery of the new continent, when Saavedra, a Spaniard, proposed to cut a canal through the Isthmus of Darien (1520), and only eight years later, the Portuguese Antonio Galvao indicated four different routes through the Isthmuses of Mexico, Nicaragua, Panama and Darien.

The idea of uniting the Atlantic and Pacific Oceans has never been abandoned since, and, successively or simultaneously, Spaniards, Portuguese, Englishmen, Frenchmen, Americans, Belgians, etc., have explored the American Isthmus, with the hope of finding an adequate solution to that mighty problem. Navigators, soldiers, engineers, financiers, scholars, even princes and kings, have been attracted by the desire to attach their names to that great work, and have devoted to it, time, labor and money.

Wealth and science, walking hand in hand, cannot fail to attain their goal, and after two hundred and sixty years of hard toil, the execution of that gigantic enterprise has at last been undertaken.

It is not the object of this communication to give a history or even a sketch of all the works and discoveries made by these daring pioneers; but, without in any way lessening the share of fame and glory achieved by the present promoters and directors, it must not be forgotten that they have been reaping the benefit of the explorations made by their predecessors, and that if to-day the period of execution has been opened, it is due as much to the pressing need of means of rapid communication as to the energy and ability displayed by Messrs. Wise, de Lesseps, and others.

The meeting of the "Congrès International," in 1879, the formation of the "Société Internationale du Canal Interocéanique de Panama," in 1880, and the opening of the works in 1881, are events still fresh in every memory; we will therefore enter at once into a description of the proposed Panama canal, and of the works executed up to January 1st, 1888.

The length of the canal is, from deep water to deep water, 75 $\frac{850}{1000}$ kilometers, or 47$\frac{1}{10}$ miles. Starting from Colon, on the Atlantic Coast, the canal follows the shore of Limon Bay for some three miles, and about three miles further strikes the valley of the Rio Chagres, crossing for the first time the bed of that river; then it follows the general direction of that valley up to Gamboa, a distance of 22$\frac{3}{8}$ miles. At

point, the Rio Chagres changes its course nearly at right angles, but the canal continues from here in a nearly straight line towards the shores of the Pacific Ocean, following first the valley of the Rio Obispo one of the tributaries of the Rio Chagres, for about five miles. There it has reached the back-bone of the Isthmus; no more valleys, no more "rios," but only a depression in the chain of mountains that have formed a barrier between the two Oceans. Through this, hardly two miles, passes the canal. On the western slope, the valley of the Rio Grande brings it to the sea-shore eight miles distant, and a cut in Panama Bay three miles and a half in length, is all that is now needed to reach deep water. The Rio Chagres, Rio Obispo, and Rio Grande are very tortuous, winding rivers, running with a swift current, carrying along trees and debris of all sorts, constantly forming shoals of these materials, and shifting them here and there. Properly speaking they are torrents, and their discharge varies within very considerable limits, but within very short periods of time. The Rio Chagres, for instance, has, at Gamboa, a discharge of 2,500 gallons per second during the dry season, but this increases to 43,000 gallons per second during the wet season, and is known even to have been 130,000 during freshets. These freshets are very rapid; it is a common occurrence for this river to rise thirty feet in a few hours and there are on record, though fortunately not frequent, instances of sudden rises of fifty feet.

The plan at first proposed by Mr. Wise was to create in rear of Gamboa an immense reservoir, of a sufficient capacity to hold the water coming from the upper part of the river during these freshets, with outlets allowing a discharge of 43,000 gallons per second. The creation of that basin would have necessitated the erection of several dams, the main one being nearly one mile in length, one hundred and fifty feet in height, seven hundred and ninety feet in width at top, and three thousand one hundred and fifty feet at the base. As the bed of alluvial deposit is at that point ninety feet thick, this dam was to have been built of clay and rock, without any more masonry than would have been necessary for the sluice ways. The maximum height of the water in rear of this dam would have been 125 feet. Twenty-five millions of cubic yards of materials had been calculated as being required for this work.

That solution, however, has since been discarded by the engineers as too bold, while at the same time it did not afford a sufficiently satisfactory settlement to the difficulty. It was finally decided not to admit any water course into the canal, but to dig beds for the rivers on both sides. However a very large dam will have to be built at Gamboa, but without

any sluice ways, the course of the Rio Chagres being deflected through a new channel, on the left side of the canal. (1).

This dam will be about 80 feet in height, 1,600 feet in length, and 80 feet in width on the top, its two extremities butting against the cerros Santa Cruz and Obispo. It will be built of the materials excavated from the heavy cuttings near by, the core being made of clay and the outer surfaces covered with broken rock. The slopes adopted for the sides will be 2 to 1 for the upper one, and 5 to 1 for the lower one.

From Gamboa to the sea, the 10 deflections of the Rio Chagres aggregate 20½ miles in length, the total fall of the river being some 45 or 50 feet.

The Rio Obispo flows into the Chagres near Gamboa, but on the right side of the canal, and its course generally lies on that side up to the point where it runs also at right angles to its former direction, on the left side of the canal. This river will be deflected on the right side of the canal, down to the sea, or rather down to the point where the actual bed of the Rio Chagres leaves the line of the canal to run towards Limon Bay.

This will necessitate the building of a flume bridge at kilometer 52, thrown across the canal at the height of 180 feet above sea level. This flume bridge, designated on the plan as "2nd pont-bâche," will carry the waters of the Rio Obispo and of Lake Lapita by means of two troughs, each 6 ft. 8 in. x 6 ft. 8 in. A similar bridge will be built at kilometer 48 $\frac{5}{1000}$ to carry over the canal the waters of the Lake Margarita and of the Rio Sardanilla; the height of this bridge will be 135 feet above sea level. The length of these flume bridges will be about 500 feet. All the tributaries of the Rio Chagres, coming from the right side of the canal, the Rios Caravali, Culo Seco, Baila Monos, Caimito, Trinidad, etc., will be collected in these deflections, their aggregate length being 21¼ miles.

On the Pacific Coast, the rivers will be dealt with in a similar way, the Rio Grande being deflected on the right side of the canal, and the Rios Pedro-Miguel, Caimitillo, Cardenas, etc., will be deflected on the left side. A few only of these last deflections have been located, aggregating 4¾ miles in length.

---

(1) The starting point of the centre line of the Panama Canal is at Colon, and all the works, deflections, etc., are also numbered from the same point, and referred to as being on the right or left side of the canal, as they would be on the right or lefthand side of a man walking along the centre line towards Panama.

There are also other incidental works, as deflections of the Panama Railroad, at such places where the canal or the deflections of rivers are interfering with the railway track. These will be six in number, and will aggregate about 7½ miles in length. A swing-bridge will have to be built across the canal near San Pablo, between kilometers 35 and 36, and another will be thrown across the canal near Pedro Miguel between kilometers 59 and 60.

The dimensions adopted for the tide level canal were:

Width at bottom..... 72 feet.
Depth of water below mean sea level..... 29 ft. 6 ins.
Slopes from bottom to 6 ft. 7 ins. above water, uniformly.. 1 to 1
Width of berms on each side..... 6 ft. 7 ins.
Slopes above the berms, according to the nature of the ground, generally from 1 in 1 to 1 in 4.

Near Panama, a pair of tidal gates would have in any case been necessary on account of the difference in the height of the tide in the two oceans. At Colon the difference of level between high and low tide is only 2 feet, while it is 20 feet at Panama. Consequently, the Panama end of the canal, beyond the tidal gates or lock, will be deepened to 36 feet below mean sea level.

Following in its course the bottom of the valleys, and running between the cerros, the canal has, as before stated, a length of 47 $\frac{13}{16}$ miles, while the distance between its two extremities, measured in a straight line, is but 40½ miles.

Of these 47 miles, 25 $\frac{44}{16}$ miles are tangents, while the balance, or, 21 $\frac{66}{100}$ miles, is composed as follows:

2	curves of	4,000	metres	radius,	aggregating	1.28 miles.
3	"	" 3,500	"	"	"	4.44 "
10	"	" 3,000	"	"	"	12.39 "
4	"	" 2,500	"	"	"	3.55 "

The harbour of Colon, near the bottom of Limon Bay, is far from being safe and secure, and it is the intention of the canal company to enlarge that entrance of the canal to a width of 1650 feet for a distance of 2½ miles. This harbour protected at its entrance by a terre-plein formed of the materials coming from the excavation of the canal will afford to the ships a much needed protection, and at the same time will be very valuable for the local commerce. The buildings of the company in Colon are erected on that terre-plein, on which stands a colossal statue of Christopher Columbus, the only work of art in the country.

A meeting basin, 2½ miles long, will also be provided at some nineteen miles from Colon, and another one eighteen miles further on, on the western slope.

A detailed geological description of the different formations met on the line of the canal would go far beyond the limits of this succinct sketch in which a mere mention of the principal features of the Panama Canal Works is all that can be attempted. However, briefly described, the course of the canal runs for a distance of 27 miles through mud, sand, gravel, peat, unctuous and arenaceous clay, meeting occasionally with beds of soft calcareous tufa, argillous schist, limestone conglomerate, sandstone and argilite, the aggregate length of these rocky formations being only $3\frac{1}{2}$ miles. Then for 13 miles, the cut runs through a mass of hard, igneous, vitreous and metamorphic rocks, in which predominate compact limestone, volcanic aglomerates, hard sandstone, basalts, argilite, carbonaceous shale, arenaceous tufa, etc., covered however with a thick layer of clay and earth. On the western shores of the Isthmus, and in Panama Bay, the canal runs through beds of clay, sand, gravel, mud and shells, for a distance of some seven miles.

At the end of the year 1887, just seven years after the beginning of the works, the Panama Canal Company found itself in a very difficult position. It had already incurred liabilities far exceeding the cost of the canal as estimated by the congress of Paris ($209,000,000); its financial department required some 15 or 16 millions of dollars annually; the treasury was nearly empty; seven twelfths of the time allowed by the charter to complete the works had gone by; and yet, there was hardly one quarter of the excavation done and that even the easiest portion.

It is true that immense preparations had been made. The Isthmus, and let this be borne in mind, enjoys the well deserved reputation of having the most insalubrious climate; there were no population,no agriculture, no manufactures, no trade, nothing, absolutely nothing there to depend upon or to help in the construction of the canal, except however the Panama Railroad. Everything had and has to be imported: laborers, contractors' plant, dwelling houses, all sorts of materials and supplies, even meat, butter, milk and water! To do this alone denotes on the part of the promoters indomitable energy and unshaken faith in the ultimate success of their enterprise. Blunders may have been committed, money may have been spent with a lavish hand, but such faults are inherent in all great works and almost beyond man's control.

The plant alone comprises: Fifty steam dredges of the most powerful built; thirty tugs; two hundred scows; one hundred and twenty steam excavators; two hundred locomotive engines; six thousand large dumping cars; two hundred miles of standard-gauge railway;

one hundred and ten miles of narrow gauge portable railway, with seven thousand small dumping cars; one hundred and thirty portable engines; five hundred pumps; three large work-shops splendidly equipped; twenty conveyors; over 11,000 lengths of large pipes for the transportation of excavated materials; dwelling houses, offices, shanties, of all descriptions and without number; and finally, two large hospitals, one of them, the Panama hospital, being certainly one of the best equipped in the world, as it is also probably one of the most costly.

The climate of the country is not only fatal to man and beast, it also exerts a destructive action on all kinds of materials, and consequently a constant supply of new plant has to be kept up.

The force employed on the works may be estimated at twenty thousand men, mostly Jamaicans. They stand the rigour of that deadly climate better than any other race, and the yellow and Panama fevers do not make such havoc among them as among the laborers of white or yellow extraction.

One of the most important sources of delay, as one of the most uncontrollable, is that the dry season lasts only from four to five months, and that perforce, the works have to be partly suspended during the wet season. Then occur sudden freshets; the ground, thoroughly soaked, slides in all directions; the railway tracks are carried away or sink under the weight of the cars; and above all, exposure to the rain is, to a European, nearly equivalent to a death warrant.

However, let the enormous difficulties that have been successfully surmounted be almost without number, the preparations be as extensive, thorough and complete as possible, yet the fact remains that, by the end of 1887, the hope of completing the tide level canal, within a reasonable time and at a remunerative cost, had to be given up, and it was then resolved to modify the originally contemplated plan and to *provisionally* resort to another solution. The modifications adopted consist of the temporary substitution of a lock canal for the tide level canal, and the reduction of the draught of water in the canal to 27 feet, all through, except at the entrance at Panama.

Ten locks, 590 feet long, 60 feet wide, will be built, six of them having a fall or rise of 36 ft. 1 in., three a fall or rise of 26 ft. 3 in., and one of 35 ft. 3 in., on account of the tide on the Pacific coast. The total rise will be 160 ft. 9 in. The locks are not to be located on the centre line of the canal, but either to the right or to the left, so as not to interfere with the subsequent deepening and widening. They are also so arranged that corresponding locks on either side of the summit reach

have equal falls, and consequently may be successively done away with by pairs.

The location of the locks has been determined by the nature of the ground: Lock No. 1 will be built on a bed of limestone; Locks Nos. 2, 3, 4, 5, 6, on hard sandstone; Locks Nos. 7 and 8 on conglomerate; Lock No. 9 on dolerite, and Lock No. 10 on hard tufa.

It is estimated that some fifty millions of cubic yards of material will have to be removed to complete the lock canal, and the transformation of this to the tide level canal will embrace the removal of an additional mass of from 65 to 100 millions of cubic yards of material, according to the nature of the ground and the slopes adopted for the cuttings.

The alimentation of the lock canal will not offer any very serious difficulty. The waters of the Upper Obispo, and Upper Rio Grande will be utilized, and, when necessary, the water will be pumped from the Rio Chagres into the upper reach. It has been estimated that for a daily traffic of ten ships, this service will be effectually insured by the action of steam pumps of 4,000 horse-power. But this lock canal is at best a lame solution; the expenses connected with its maintenance will be very heavy, embracing, besides the pumping, constant dredging, necessitated by the growth of sub-marine vegetation and by the large proportion of alluvial matter carried by the waters of the rivers of this region; the locks would have to be frequently renewed; therefore it is understood that these last described works, are only provisional.

The principal features of the charter of the Canal Company are:

A grant from the Colombian government of five hundred thousand hectares of land, with all the minerals therein, besides all the ground required for the canal, wharves, roads, stations, buildings of all description, etc., provided it is not private property.

On the other hand, the Colombian government is to enjoy the free use of the canal and a participation of at least five per cent. in the gross earnings of the Company, this, however, being never less than two hundred and fifty thousand dollars per year.

The company also agrees to bear all the expenses connected with the maintenance of the military forces required to insure the security of the interoceanic transit.

At the end of ninety-nine years, computed from the opening of navigation, the canal and all its appurtenances will become the property of the Colombian government.

TABLE showing the lengths of the reaches and their respective levels:

N.B. The datum or zero level is the mean level of the sea.

	Lengths in miles.	Levels of bottoms of reaches in feet.	Remarks.
Colon harbor.	0.84	— 27.07	From deep water to shor
1st Reach.	14.13	— 27.07	Including Lock No. 1
2nd "	8.94	— 0.82	" " No. 2
3rd "	4.16	25.43	" " No. 3
4th "	1.48	61.52	" " No. 4
5th "	2.61	97.61	" " No. 5
6th "	3.92	133.69	Summit reach.
7th "	0.33	97.61	Including Lock No. 6
8th "	0.31	61.52	" " No. 7
9th "	0.81	25.43	" " No. 8
10th "	1.37	— 0.82	" " No. 9
11th "	4.35	— 36.09	" " No. 10
Panama Bay.	3.85	— 36.09	From shore to deep water.

DEFLECTIONS.

	Left Bank.		Right Bank.	
Nos.	Lengths in miles.	Rivers deflected.	Lengths in miles.	Rivers deflected.
1	6.13	Rio Chagres.	1.43	Rio Obispo,&c.
2	5.21	"	.37	"
3	1.14	"	3.84	"
4	.45	"	2.05	"
5	.85	"	1.63	"
6	1.22	"	2.19	"
7	2.79	"	.57	"
8	.38	"	1.24	"
9	1.12	"	2.55	"
10	.98	"	.23	"
11	1.24	Lk. Margarita.	.05	"
12	0.64	" Lapita.	.18	"
12bis	.57	Rio Obispo.		
13	.84	Rio Pedro Miguel.	.83	"
14			1.68	"
15				
16			1.18	Rio Grande.
17			2.73	"
Totals..	23.56		22.75	

DISTANCES BETWEEN SOME HARBOURS, IN NAUTICAL MILES.

	Via Cape Horn.	Via Panama Canal.	Difference.
London to San Francisco,	13,795	8,135	5,660
" — Honolulu,	13,915	9,556	4,359
Liverpool — San Francisco,	13,678	7,897	5,781
Le Havre — "	13,627	7,949	5,678
Bordeaux — Valparaiso,	8,675	7,239	1,436
New York — "	8,550	4,574	3,976
" — Panama,	11,057	1,966	9,091
" — Callao,	9,791	2,333	6,488
" — Guyaquil,	10,441	2,808	7,633
" — San Francisco,	13,334	2,468	9,056

From the Drawings accompanying this paper, Plates I & II have been prepared.

DISCUSSION.

In answer to various questions propounded by Messrs. Hannaford, J. Kennedy, Peterson, Parent and Prof. Bovey, Mr. Deniel replied as follows:—

By the first January, 1888, the amount of excavation completed ranged between 30 and 40 millions of cubic yards, and there were still about 150 millions cubic yards to be removed; roughly speaking, about one-fourth of the work had been done.

Probably no one really knew the total cost of the work remaining to be finished, as it was very difficult to make an estimate.

He thought that the difficulty of completion did not lie in the work itself, but in the matter of raising the money. The great mistake made by the promoters had been in beginning the work with a small capital, about $60,000,000, whereas their liabilities had already reached some $300,000,000.

He considered that $100,000,000 would be sufficient to finish the work, which would undoubtedly stand, as there would be no danger from freshets, and the canal would only be destroyed by an earthquake

The work was superintended by the Panama Canal Co., which had. given contracts to the following firms:

Société de Travaux Publics et Constructions, 15 rue Louis-le-Grand, Paris.

MM. Vignaud, Barbaud, Blanleuil & Cie., 19 rue Louis-le-Grand, Paris.

MM. Baratoux, Letellier & Cie., 4 rue de Rome, Paris.

MM. Artigue, Sonderegger & Cie., 1 rue de la Bourse, Paris.

M. Jacob, 11 Place du Commerce, Nantes.

The American Contracting & Dredging Company, New York.

The canal is divided into five divisions; each one under the charge of a divisional engineer and staff, appointed by the Company.

The first division runs from Colon to kilometer 26 $\frac{3}{10}\frac{5}{0}\frac{0}{0}$. The works, principally dredging, are carried out by the American Contracting & Dredging Co., for the canal, and by Mr. Jacob, for the deflections of the Rio Chagres on the left bank of the canal.

The second division runs from kilometer 26 $\frac{3}{10}\frac{5}{0}\frac{0}{0}$ to kilometer 44. The contractors are MM. Vignaud, Barbaud, Blanleuil & Cie. Their plant consists of excavators, conveyors, dredges, large and small dumping

cars, etc. The steam excavators and conveyors do not do as much work as was expected of them. They do not work much more than one-third of the time, while the negroes work at least two thirds.

The third division runs from kilometer 44 to kilometer 53 $\frac{6}{1}\frac{0}{0}\frac{0}{0}$. There lies the heaviest part of the work. The contractors are the Société de Travaux Publics et Constructions. They use very large and heavy plant, steam excavators, broad gauge railways, etc.

The fourth division runs from kilometer 53 $\frac{6}{1}\frac{0}{0}\frac{0}{0}$ to kilometer 57. The contractors are MM. Artigue, Sonderegger & Cie. This division, as the preceeding one, is mainly through rock cutting, and the plant employed is of the same description in both cases. The work here is carried on day and night with the aid of the electric light.

The fifth division runs from kilometer 57 to kilometer 74, $\frac{5}{1}\frac{0}{0}\frac{0}{0}$ in Panama Bay. It is under contract with MM. Baratoux, Letellier & Cie., and it is mainly dredging. In the Panama Bay the material dredged was very soft, and consequently the work has been easy, but the sand for a long time kept running into the cut in such quantity that once, during a whole week, one of the elevator dredges employed there was kept at work on the same spot, its buckets coming up full all the time. Consequently the width of the cut in the Bay of Panama is considerably larger than elsewhere. However, this portion of the work, that is, from deep water to La Boca, is now completed to the full depth and width.

The heavy plant, comprising dredges, excavators, cars, rails, engines, dwelling houses, etc., belongs to the Panama Canal Company, and is rented by the contractors, who furnish only the small tools, such as picks, shovels, crow-bars, drills, etc.

The deepest cut is at the Culebra. On the centre line, it measures there 107 metres above canal bottom, but the left side of the cut starts from a point 70 metres higher, near the summit of the Cerro Culebra, and at a distance of 189,84 metres from the centre line. By the adoption of the new plan, the depth will be reduced to about 180 feet on the centre line. The centre line of the new canal will be the same as at present, but the locks will be located either on the right or on the left of it, in order to interfere as little as possible with the contemplated subsequent deepening and widening.

The Cerro Culebra is a hill of some height. It does not slide bodily towards the canal as it has been wrongly reported, but sinks, and produces heavings in the canal, and occasional slidings. This, however, could not go on for ever, as the core of the mountain is made of rock;

it would have to stop some time, but till then, there was nothing to do but to keep removing the material. These heavings were at one time so sudden that it in the morning, the excavators, cars, rails, etc., were frequently found on a considerably higher level than that on which they had been left on the previous evening, and, of course, more or less damaged.

He thought, however, that the trouble would soon stop; there was not as much movement as there had been. In consequence of these disturbances, the cross sections had had to be extended 3 or 4 hundred feet beyond the summit of the slope, in order to have at least an approximate idea of the quantity of material removed by the contractors. There are bench-marks built of masonry on both sides of the canal, and these are checked by similar bench-marks built along the line of the Panama Railroad.

The idea of the high dam has been given up, but there will still be one of some 80 feet in height (see page 5).

The work in the deflections was not different from the work in the canal, nor did it entail any more difficulty.

The Panama Canal Co. does not do any of the work, but gives it out to the large contractors who generally sublet it to smaller companies. The work is measured up by the engineers of the Panama Canal Co., and by the engineers of the contractors, always acting together and checking each other. One source of delay in the progress of the works has been in the periodical freshets of the rivers, especially of the Chagres. The custom was to give a sub-contractor either one deflection or a length of canal comprised between two bends of the river. The operations usually begin about the middle of December and continue until about the middle of May, when the rainy season sets in. Naturally the sub-contractors make use of the bed of the Chagres as a spoiling ground; the river carries to the sea part of the spoil, but not the whole of it, and when it rises, it carries back part of it into the canal and the speaker has seen railway tracks buried under six feet of earth.

The speaker is not well posted on the financial position of the company, nor as to its expectations, but he has read that the transoceanic traffic had been estimated at 6,000,000 tons annually. The Canal Company, according to its charter, is allowed to charge 15 francs or $3 per ton, and at these figures it would have an income of $18,000,000 per year. This seemed reasonable, but it is well to understand that the *ton* at the Panama Canal is not the same as elsewhere. In France, for instance, the official tonnage of a sailing ship is obtained by

multiplying together the three dimensions of the hull[1] in metres and dividing the product by 3.80 ; for steamships, the result thus obtained is further reduced by 40 per cent. But, at Panama, the outside length and greatest width, at water line, and the draft (in metres) will be multiplied together and the result will be the number of tons on which the tolls will be collected. If, therefore, these rules were to be adhered to, the duty at Panama would be nearly trebled and would amount to about $9 per ton.

Replying to Mr. Hannaford, who asked where the money was coming from to complete the works, the speaker said that he had no doubt the people of France would furnish the required capital. The company's liabilities were to-day, according to Mr. deLesseps himself, three hundred millions of dollars; but this enormous sum does not represent the money actually spent on the works. The discount on the loans had been as high as 40 per cent, as for instance, in the loan of 1883, for 300,000,000 francs, which produced 171 millions without any deduction for brokerage, etc. Up to 1884 (he had not the figures for a later date), the company had assumed liabilities for 918 millions of francs, while it had only received 734 millions.

The company had then for years been paying interest on money they had never received, and that could not be kept up long without something like a crash occurring. However, the work already done and the plant on the Isthmus could not be estimated at less than 100 million dollars. If the works were suspended all this would be lost, but with another 100 millions of dollars applied to the works the canal could be opened to traffic and all then could be saved.

Replying to Professor Bovey as to the probability of the Canal being taken in hand by Great Britain, France and the United States, as an international work—

Mr. E. Deniel said that would be contrary to the charter of the company which forbade the alienation or mortgage of any of its privileges to a foreign nation or government; any transgression of this would nullify the charter. The company had 12 years in which to do the work, so that it has now about five years to complete the canal, and it does not seem that a momentary suspension of the operations would affect its rights. There is also a clause in the charter providing for a further extension of six years, if at the end of the first twelve years the works are so far advanced that their completion within the extended period may appear probable.

The charter does not make any mention of the canal being either a

sea level or lock canal. By the modification made in the former scheme, from a sea-level to a lock canal, the proportion of work already done has increased from one quarter to one-half of the total amount, so that the completion of the canal which was doubtful even during the eighteen years, is now possible and even probable within the twelve years.

The money already advanced has come principally from France; very little having been contributed by the United States or other countries.

He also thought the people of France would advance the additional amount required. It is well to know that it is very difficult to ascertain the exact state of things concerning the canal and the financial condition of the company. Mr. de Lesseps had very powerful enemies, even in France, ready to take hold of the enterprise if they had the opportunity. When the speaker was in Panama last winter, he wondered of what use the large contracting firms with their expensive staff of engineers, accountants, clerks and other employees, could be, since the work was actually performed by the sub-contractors, but he was told that nobody there expected to see the canal company carry out the works to the end; but if it could push it far enough, then, when the money would become scarce, the contractors could and would bring their respective contracts to completion and be recouped out of the first proceeds of the canal. All the firms above mentioned are backed by large French banking establishments which could come forward in an emergency.

On 1st Jan., 1888, Messrs. Slaven & Co., were far from having finished their work, having then done about three-fifths of it. It was all dredging through mud, sand and clay, with the exception of four ledges of rock aggregating about two miles in length. The plant used by Messrs. Slaven & Co. (American Dredging and Contracting Co.) has been described above, and consists of elevator dredges. The materials excavated are deposited on each side of the canal, through the "long couloir." The result of the operations has been the drainage of the marshes and the consolidation of the ground through the region traversed by the canal in the neighborhood of Colon. The works had been opened simultaneously at different places, the dredges having been sent up by the Rio Chagres, and, when in position, dredging in the line of the canal on both sides of the river.

The plans (plate I) exhibited show all the work done in the canal and deflections up to January 1st, 1888, the work remaining to be done

to complete the lock canal, and the work subsequently to be done to complete the sea level canal.

Mr. Deniel could not give any information as to the high charges on ocean freights, or whether such charges would prove prohibitive. He had not studied all the different aspects of the question of the Panama Canal, but simply the engineering features of the enterprise.

The following statement as giving more detailed information concerning the financial position of the Panama Canal Company, may be of interest to the members :—

On January 1st, 1888, the liabilities of the company amounted to $329,505,100, as follows :

Original capital							$60,000,000
Loan of 1882	bearing	interest	at	5	per	cent	25,000,000
" 1883	"	"		3	"		60,000,000
" 1884	"	"		4	"		34,129,200
" 1885	"	"		4	"		6,837,500
" 1886	"	"		3	"		91,760,000
" 1887	"	"		3	"		51,778,400
					Total		$329,505,100

From which must be deducted :

Promoters' shares (10,000 at $100)	$1,000,000	
Discount on loan of 1882	3,125,000	
" " 1883	25,800,000	
" " 1884	8,809,500	
" " 1885	1,765,000	
" " 1886	51,462,505	
" " 1887	28,996,355	120,958,360
Leaving a sum of		$208,546,740

Representing the cash raised up to that date. The amount paid up to the same date on interests, amortization, brokerage, etc., etc., is about :

Interest paid on original capital	$13,500,000
Interest and amortization on loan, 1882	8,500,000
" " " 1883	11,784,000
" " 1884	6,061,347
" " 1885	815,030
" " 1886	4,588,600

Brokers' and bankers' fees, say 2½ per cent.	8,237,628	
Cash paid for charter to promoters.....	1,000,000	
Preliminary expenses.....	4,520,000	
Panama Railway (68,534 out of 10,000 shares).....	18,775,000	77,781,605
Leaving a sum of.....		$130,765,135

to defray all expenses such as salaries, buildings, plant, excavation, etc., etc., including $25,000,000 for the construction of the locks.

Thursday, 17th January, 1889.

ANNUAL GENERAL MEETING.

SAMUEL KEEFER, President, in the Chair.

MORNING SESSION.

The notice convening the meeting having been read, it was moved by Mr. H. F. Perley, seconded by Mr. R. Forsyth and resolved,

"That Messrs. A. Brittain, G. A. Mountain and F. Chadwick be requested to act as scrutineers for the election of the President, Vice-Presidents, Treasurer, Librarian, Secretary, and other Members of Council for the year 1889."

It was moved by Mr. W. J. Sproule, seconded by Prof. McLeod,

"That the scrutineers be instructed to make a return of all the names receiving votes, together with the number of votes cast in each case, and that such return be published in the minutes of the annual meeting."

It was moved in amendment by Mr. P. A. Peterson, seconded by Mr. H. A. F. MacLeod,

"That the returns shew only the names of the officers elected."

The amendment, on being put to the meeting, was carried.

It was moved by Mr. St. G. Boswell, seconded by Mr. G. H. Garden and resolved,

"That Messrs. W. McL. Walbank, T. W. Lesage and P. L. Naismith be requested to act as scrutineers of the ballot for the proposed Amendments to the By-Laws."

The minutes of the last annual meeting having been read, it was moved by Mr. W. J. Sproule, seconded by Prof. McLeod,

"That the minutes be amended in accordance with the resolution requiring the scrutineers to make a return of all the names receiving votes, together with the number of votes cast in each case."

It was moved in amendment by Mr. J. Kennedy, seconded by Mr. H. Wallis,

"That the minutes as read be adopted."

The amendment was carried.

The Secretary next read the Annual Report of the Council, which was as follows:—

ANNUAL REPORT.

ROLL OF THE SOCIETY.

The Council notes with satisfaction that during the past year the membership of the Society has steadily increased. The elections comprised, *twenty-eight* members, *nineteen* associate members, *twenty-four* associates, and *thirty-two* students, while from various causes *nineteen* have been removed from the list, the net increase for the year being *eighty-four*.

The resignations were:—

Member, W. Barclay Snow.

Associate, Andrew T. Drummond.

During the same period the Society has lost one member by death, R. Boag, a memoir of whom has appeared in the Transactions.

The total number on the list at the present date includes, *two* honorary members, *two hundred and fifty-nine* members, *eighty-seven* associate members, *forty-seven* associates, and *one hundred and forty-five* students, or *five hundred and forty-two* in all.

Experience has made it evident that more attention should be given by members to the qualifications required for admission into the several classes, and it would much facilitate the work of the Council if a proposer would communicate to the Council, through the Secretary, his opinion as to the proper classification of a candidate.

It should also be borne in mind that in the case of the students, it is absolutely necessary that the candidate should produce satisfactory evidence of a general education, as required by By-Law 18, for the admission of students who do not possess a proper degree of culture would lower the tone of the Society.

It is encouraging to find that eminent engineers, both in England and the United States, are enrolling themselves as members of our Society. It is a mark of its growing importance and surely a presage of its future success.

The Society is to be congratulated on the opening of the list of Honorary Members.

The first name on the list is that of,

His Excellency the Right-Honourable Lord Stanley of Preston, G. C. B., P. C., Governor General of the Dominion of Canada, &c., &c., who, eminent as a statesman, and fully recognizing the importance of great Public Works, has followed with deep interest the progress of engineering science.

The second name on the list is that of,

Sir William Dawson, LL.D., F.R.S., K.C.M.G., Vice-Chancellor and Principal of McGill University, whose name would honour the roll of any scientific Society, and who was the first to make a practical move in this country, in the direction of technical education, by the establishment at McGill College of a department of engineering, in the year 1856.

In connection with this, it is of interest to know that our *first* President was also the *first* Professor of Engineering.

ORDINARY MEETINGS.

There have been *sixteen* Ordinary meetings of the Society during the year 1888, at which the following papers have been read:—

From January to June:

On the "Telephone," by F.N. Gisborne; on the "Six-foot Wooden Conduit for the Toronto Water Works," by T. J. McMinn; on "Concrete as a Substitute for Masonry in Bridge Work," by M. Murphy; on "Railway Accidents and a Railway Commission," by A. T. Drummond; on the "Canadian Pacific Ry. Bridges at Ste. Anne and Vaudreuil," by C. E. W. Dodwell; on "Cedar Block Carriage-Ways," by A. Macdougall; on "Electric Lighting," by H. S. Thornberry; on "Masonry Arches for Railway Purposes," by W. B. Dawson.

From October to December:

On the "Sewerage System of Vancouver," by E. Mohun; on the "Evolution of the Telegraph," by F. N. Gisborne; on the "Construction of the Toronto Sewers," by C. H. Rust; on "Coal Mining in Nova Scotia," by E. Gilpin, Jr.; on "A Mine Pump Working under Heavy Pressure," by H. S. Poole; on the "Spring-Hill Collieries," by R. W. Leonard.

Particular mention might be made of Mr. Gilpin's Paper on Coal Mining, which gives an exhaustive description of the present condition of the several collieries, and which will prove a valuable addition to the mining literature of the Dominion.

Under the auspices of the Society, a public lecture upon the "Electric Telegraph and other Electrical Inventions" was delivered by Mr. F. N. Gisborne, member of Council, upon the 29th October. The lecture was one of much interest, and was listened to by a large and appreciative audience. The Council hopes, from time to time, to make arrangements for similar lectures upon scientific subjects.

The discussions upon the different papers have been most animated, and have considerably enhanced their value. They might, however, with advantage, receive still greater attention, and the Council would especially

urge non-resident members to shew their interest in the Society by sending written criticisms of the several papers.

At the conclusion of the Annual Meeting, on the 12th January, 1888, a Conversazione was held at McGill College. An important feature of this entertainment was the delivery of the Annual Address by our past President, Mr. T. C. Keefer. He most appropriately opened his address by a brief statement of the proceedings which had led to the formation of the Society, and continued with a most complete and valuable review of the important engineering works of the Dominion, severally treating them under the heads, Railway, Hydraulic, Civic, Mechanical, Mining and Electrical Engineering.

STUDENTS' MEETINGS.

There have been *three* Students' meetings, at which papers were read on the "Montreal and Maskinonge Ry.," by E. S. M. Lovelace; on the "Water-supply of the city of Charlottetown, P.E.I.," by S.R. Lea; and on "Locomotive Construction," by J. P. Tuplin.

Great care, thoughtfulness, and observation were shewn in Mr. Lea's paper, which the Council has deemed of sufficient merit to be published in the Transactions. The Council would impress on the students, the importance of making it a more regular practice to prepare papers, which will prove of no small advantage to themselves, and will fit them to become valuable members of the Society.

LIBRARY.

Since the last general meeting, a number of donations to the Library have been received, and among these mention should be made of the following:—

From The Royal Society of Canada, a complete set of the Proceedings and Transactions of the Society, up to date.

From The Institution of Civil Engineers, London, a further donation of 20 volumes, in addition to 16 vols. previously received, making a complete set of the Proceedings from vol. 59 to vol. 94 inclusive.

From the Commissioner of Patents, London, about 200 volumes of Abridgments of Specifications of Patents.

A number of valuable contributions have also been received from members of the Society.

Special reference should be made to the donations of Messrs. T C. Keefer, Past President; S. Keefer, President; H. F. Perley, Vice-President; C. Baillairgé, L. M. Clement, D. McMillan, K. Blackwell and J. Peck.

A complete list of members who have sent books, or money for the purchase of books, will be printed as soon as possible.

In addition to the above, a number of valuable and interesting photographs have been presented to the Society.

Rules for the Library and the catalogue are now in the printer's hands, and will be issued in a short time.

From these rules it will be seen that arrangements are being made, by which members residing in the Dominion of Canada may borrow certain of the books from the Library.

The Council would again remind all members of the obligations contracted by them on election to subscribe books, or their equivalent, to the Library. The proper equipment of this branch of the Society's work is most essential to its efficiency.

ACCOMMODATION.

The Society continues to use rooms at McGill University through the kindness of the Governors. Some progress has been made towards a fund for the erection of a building to meet the growing needs of the Society. The following statement will give the present condition of the Building Fund.

BUILDING FUND.

The Building Committee, appointed by the Council under the resolution passed at the last annual meeting, has, during the present year, issued two circulars, one on the 11th February and one on the 1st October. Up to the present date, 36 members, 13 associate members, 2 associates, and 17 students have identified themselves with the fund, the total sum promised being $3,281.00, of which amount $1,809.25 have been paid to the Treasurer.

The Council has been especially gratified to observe the hearty response to the circular on the part of the students.

The Council, however, feels that this important question has not attracted the consideration it deserves, and hopes that within the next few months large additions may be made to the Fund.

FINANCES.

The income for the year ended on the 31st December, 1888, amounted to $2777.64, and the general expenditure reached $1789.64, leaving a balance of $988.00, which, together with the balance of $960.92, brought forward from the year 1887, gives a total balance of $1948.92 to be carried forward.

CANADIAN SOCIETY OF CIVIL ENGINEERS.

ABSTRACT OF RECEIPTS AND EXPENDITURE FOR THE YEAR ENDING DECEMBER 31ST, 1888.

Balance from Dec. 31, 1887			$960 92	
GENERAL RECEIPTS.				
Subscriptions:—				
Arrears	$56 00			
Current	1983 00			
Advance	582 00			
Extra on local cheques	1 65	2622 65		
From Building Fund for Stationery		9 00		
Extra "Transactions" sold		97 00		
Bank Interest		48 99	2777 64	3738 56
BUILDING FUND.				
Subscriptions		1262 40		
Bank Interest		2 85		1265 25
				$5003 81

GENERAL EXPENDITURE.				
Cost of Printing Transactions, including advance proofs of papers		$757 40		
Printing and Stationery		224 28		
Postage, Messengers and Telegrams		269 68		
Expenses of Secretary		350 50		
Janitor's fee		15 00		
Office Furniture and Books		133 35		
Rent of Telephone		25 00		
Bank commission on local cheques		3 65		
LIBRARY.				
Express charges on Books			10 78	1789 64
BUILDING FUND.				
Books, Printing and Stationery				15 55
BALANCE.				
General—In Bank	$1940 92			
In Hand	8 00	1948 92		
Building Fund, In Bank		1249 70		3198 62
				$5003 81

Examined with Books and Vouchers, and found correct.

JOHN KENNEDY,
PERCIVAL W. ST. GEORGE. } *Auditors.*

HERBERT WALLIS,
Treasurer.

It was moved by Mr. E. P. Hannaford, seconded by Mr. A. Macdougall,

"That the Report of the Council be received, approved, and printed in the Transactions."

It was moved by Mr. H. F. Perley, seconded by Mr. P. A. Peterson,

"That the following members of the Society be the Committee to nominate the officers and council for the year 1889 :—

"Mr. T. C. Keefer, Past Presidents, Ottawa,
" S. Keefer " " Brockville,
" R. Forsyth, Chairman, Montreal.
" P. S. Archibald, Moncton, N. B.
" E. A. Hoare, Quebec.
" H. B. Smith, Vancouver, B. C.
" J. H. Taylor, Kingston, O."

It was moved in amendment by Mr. W. J. Sproule, seconded by Professor McLeod,

"That the names of nominees be written on the blackboard and be voted upon by the meeting."

The amendment was lost. The main motion was put to the meeting and declared carried.

It was moved by Mr. Surtees, seconded by Mr. E. A. Evans, and resolved,

"That the Secretary be instructed to convey to the Governors of McGill University the thanks of the Society for the accommodation generously provided in the University Buildings."

It was moved by Mr. E. Wragge, seconded by Mr. G. H. Garden, and resolved,

"That the Secretary be instructed to convey to the Board of Harbour Commissioners the thanks of the Society for the use of an office in their building."

It was moved by Mr. Macdougall, seconded by Mr. J. H. Taylor, and resolved,

"That the Secretary be instructed to convey to the management of the Grand Trunk, Canadian Pacific and Intercolonial Rys., the thanks of the Society for travelling facilities."

The scrutineers announced the following as the result of the ballot for amendments to By-Laws:—

(*a*) *Instead of* 4 *read*....."*The Corporate Society* shallconsist of all those persons who had been admitted previous to its incorporation, together with all those who may be admitted thereafter. They shall be classified as Honorary Members, Members, Associate Members, Associates and Students. Honorary Members shall not be subject to

fees or dues, and shall not be entitled to vote. Associates and Students shall possess all the rights and privileges of Members and Associate Members, except the right to vote or to hold any office but that of *Librarian*."—

Carried by 98 *per cent. of the votes*

(*b*) *Instead of* 6 *read*..." *The Officers* of the *Society* shall consist of a *President, three Vice-Presidents, Treasurer, Secretary, Librarian, Honorary Councillors* and *fifteen Councillors*, of whom not more than three may be Associate Members. At the Annual General Meeting, a nominating Committee shall be appointed, composed of five members, and of four past Presidents (or such smaller number as there may be) who are neither *elective* officers nor *candidates* for *office*, whose duty it shall be to select the names of such members as in its opinion are qualified to fill the offices of *President, Vice-Presidents, Treasurer, Secretary, Librarian* and *Members of Council*, for the ensuing near, and who shall signify to the Committee their willingness to accept their several nominations. The list shall contain twenty-six names, viz.: one for President, three for Vice-Presidents, one for Treasurer, one for Secretary, one for Librarian and nineteen for Councillors. Such names shall be forwarded to the Council, not later than the first day of the following November, and thereupon a copy of the list of names shall be sent to each member of the Society for his guidance in voting. The Chairman of the Committee shall be *resident* at the *Head-quarters* of the Society. The nomination list shall be signed by a majority of the members of the nominating Committee. Any five members, not officers of the Society, may present to the Council, on or before December 1st, a list of names proposed by them for officers, which list or lists shall also be issued for ballot "..... .... *Carried by* 96 *per cent. of the votes.*

(*c*) *Instead of* 8 *read*..." *The President*, or, in his absence, one of the Vice-Presidents, shall preside at all meetings of the Society. In the event of the absence of the President and of all the Vice-Presidents, the meeting may select any member as chairman, the preference always being given to a member of Council."

" Past Presidents shall be Honorary Councillors."

Carried by 98 *per cent. of the votes.*

(*d*) *Instead of* 10 *read*..." *The Treasurer* shall have charge of the funds of the Society, and shall receive all money, pay all accounts and orders approved of by the President, or by the Chairman of the Finance or of the Library Committees. He shall also deposit and invest the

funds of the Society in its name, and always with the approval of the Council. All accounts exceeding $10 shall be paid in cheques, which shall be signed by the Treasurer and countersigned by one member of the Finance Committee."

Carried by 98 *per cent. of the votes.*

(*e*) *Instead of* 12 *read...*" *There shall be a Council* consisting of the President, Vice-Presidents, Secretary, Treasurer, Honorary Councillors and Councillors, and of this Council five shall constitute a quorum. The *duties* of the *Council* shall be.....to have a general supervision of the affairs of the Society, to prepare by-laws, to approve and classify candidates before submitting their names to ballot, to fill up vacancies as they occur amongst its members, to apply the funds in the Treasury, to recommend the amount of the appropriations for specific purposes, and to present a report at the annual meeting on the affairs of the Society, embracing the report of the Treasurer. *In no case* shall the Council incur any expenditure for salaried officers or for extraordinary purposes, unless previously authorized to do so at the annual meeting, or at a special general meeting. The Council shall meet as often as the business of the Society may require."

Carried by 98 *per cent. of the votes.*

(*f*) *Instead of* 41 *read.....New By-laws* or alteration or repeal of existing by-laws may be made in the following manner: *Notification of proposed new By-laws* or alteration shall be given to the Council, signed by at least ten Members or Associate Members, not later than three months before the date of the annual meeting.

The Council shall issue *notice* of the *proposition*, specifying the particular new by-law or alteration or repeal of any existing by-law, which may be thus recommended, and submit the same to vote by letter ballot, not less than two months before the annual meeting, the ballot to be taken on or before the date of the annual meeting, and not less than two-thirds of the votes cast shall be required to effect any change. *The Council* may also propose new By-Laws, or alterations, or repeal of existing By-Laws, and may submit the same to vote by letter ballot as above."

Carried by 98.4 *per cent. of the votes.*

It was moved by Mr. H. F. Perley, seconded by Mr. D. MacPherson, and resolved,

"That the thanks of the Society be presented to the scrutineers of the ballot for the Amendments to the By-Laws, for the satisfactory manner in which they had discharged their duties, and that the ballot papers be destroyed."

AFTERNOON SESSION.

The afternoon session was opened with the President's Address, which was read by the Secretary.

It was moved by Mr. E. A. Evans, seconded by Mr. E. E. Perrault, and resolved,

"That the thanks of the Society be presented to Mr. Herbert Wallis for his services as Treasurer during the year 1888."

It was moved by Mr. G. A. Mountain, seconded by Mr. St. George, and resolved,

"That the thanks of the Society be presented to Mr. F. Chadwick for his services as Librarian during the year 1888."

It was moved by Mr. H. F. Perley, seconded by Mr. W. P. Anderson, and resolved,

"That the thanks of the Society be presented to Professor Bovey for his services as Secretary during the year 1888."

Messrs. Wallis, Chadwick and Bovey having made appropriate replies, thanking the Society for its expression of approval, the Secretary next read the report of the Scrutineers for the election of the officers and members of Council for the year 1889, which showed that the following had been duly elected as,

President.

Colonel Casimir S. Gzowski, A.D.C., Toronto.

Vice-Presidents.

Edmund P. Hannaford, Montreal; Henry F. Perley, Ottawa, P. Alexander Peterson, Montreal.

Treasurer.

Herbert Wallis, Montreal.

Librarian..

Francis Chadwick, Montreal.

Secretary.

Henry T. Bovey, F.R.S.C., Montreal.

Members of Council.

G. F. Baillairgé, Ottawa.
J. Davis Barnett, Stratford.
Kennet W. Blackwell, Montreal.
St. George J. Boswell, B.A.Sc., Quebec.
Francis R.F. Brown, Montreal.
Granville C.Cunningham, Toronto.
Edwin Gilpin, Jr., F.R.S.C., Bedford, N.S.
Frederick N. Gisborne, F.R.S.C. Ottawa.
William T. Jennings, Toronto.
John Kennedy, Montreal.
George A. Keefer, Vancouver, B.C.
Brian D. McConnell, Montreal.
Martin Murphy, Halifax, N.S.
E. Wragge, Toronto.
J. Emile Vanier, Montreal.

The retiring president, Mr. Samuel Keefer, having left the Chair, it was taken by the president elect, Colonel C. S. Gzowski, A.D.C.

It was moved by His Excellency the Right Honorable Lord Stanley, seconded by Sir Wm. Dawson, and resolved,

"That the thanks of the Society be presented to Mr. S. Keefer, for the valuable and interesting address he has this day delivered, and for his constant attention to and active interest in the welfare of the Society during the time he has occupied the President's chair."

Mr. S. Keefer replied, thanking the Society for its expression of approval.

It was moved by Mr. A. Macdougall, seconded by Mr. R. Forsyth, and resolved,

"That the thanks of the Society be presented to the scrutineers for the election of officers and members of Council for the year 1889, for the satisfactory manner in which they had discharged their duties, and that the ballot papers be destroyed."

The meeting was then adjourned.

PRESIDENT'S ADDRESS.

It is my first duty to you gentlemen, the members of this Society, to thank you for the honor you have conferred on me by electing me to the presidential chair for the past year,—the highest position in his profession a civil engineer can occupy,—and I feel the compliment all the more, inasmuch as to most of you I was personally unknown. I must claim your indulgence for any shortcomings on my part, for owing to non-residence at head-quarters my attendance at the regular meetings has not been as frequent as I had hoped, nor have my efforts for the advancement of the society been commensurate with my interest in its affairs.

It is a satisfaction to us all to know that under the able presidency of my predecessor, your first president, the society has been so well organized and its council and officers have been so zealous and efficient, that the work has been most successfully carried on. From the annual report of council it is gratifying to observe the continued prosperity of the Society, and also the interest which has been awakened in its work throughout the Dominion. Its roll of membership extends from Halifax to Victoria, and the field of its operations covers half a continent. At the end of the second year of its existence, the Society numbers 542, made up of 2 Honorary members, 259 Members, 87 Associate members, 47 Associates and 147 Students. I venture to say that none of the older engineers had any idea there were so many members of the profession in Canada as have actually joined our Society. There has been no lack of original papers, on engineering subjects, to be read at the regular meetings, which have been well attended, and the records of the Transactions show that the discussions been have actively participated in, both in person and by correspondence.

Following the traditions of the English Institution, I suppose the established usage of according to the president the privilege of delivering an address will always be followed in Canada, though, with us, the

address is given not at the beginning, but at the end of his term, which, in my humble judgment, is better. By your favor, therefore, the heavy burden of delivering an address rests on me, and truly I feel embarrassed by the conviction that there are many abler men in our society who could offer you an address more worthy of the occasion.

To an engineer who has seen much service there can be no lack of subjects from which to make a selection. In looking over the wide range of engineering activity—of which he gains a knowledge from reading, from study, and from his own personal experience—he finds too many absorbing questions to attempt their discussion, or even to enumerate them, within the time allotted to an address. Therefore, instead of attempting a survey of the whole field, it is better to confine himself to those subjects with which he is more familiar, or in which he has taken the most lively interest. I will therefore ask your attention while I refer to the following.

HYDRAULIC ENGINEERING.

As the engineering art knows no boundary lines, I may be allowed at the opening of this subject to refer to the recently constructed lock in the State of Michigan at the Sault Ste. Marie, opened for traffic in 1881. I do so because it is the finest piece of hydraulic engineering I have ever seen, and deserves prominent mention. It combines both English and American practice, is well designed and executed, and altogether successful in operation. It reflects credit on the Engineering staff of the United States Army under whose designs and supervision it was constructed.

The canal is one mile in length and sixteen feet in depth. The lock is at the lower end, and is 515 feet long between the gates and 80 feet wide in the chamber, with seventeen feet of water on the sills. The lift is eighteen feet more or less, according to the fall in the rapids between Lake Superior and Lake Huron. The gates are not set opposite to each other on the same axis, but on parallel axes twenty feet apart, so that the width between the gates is reduced to 60 feet, while in the chamber it is 80 feet, the difference being met by reverse curves on either side.

Advantage is taken of the natural water power created by the lock, to establish by the side of it an "*accumulator*" for operating the gates and valves by hydraulic pressure—in the same manner as at the London and Liverpool docks—which works as a charm.

The chamber is filled and emptied by culverts of large dimensions, under the mitre sills, without producing any disturbance of the vessel, because the tunnel or culvert runs the whole length of the chamber,

with openings at the top, so arranged as to distribute the force of the inflowing current along the centre, entirely under the vessel's keel. In 1886 I timed the Can. Pac. Ry. steamer Arthabaska passing through the lock. It took one minute and a half to close the upper gates, seven minutes and a half to empty the lock, and one minute and a half to open the lower gates, altogether from the time of entering the lock, to the time of going out of it again, the passage was made in thirteen minutes, and there was no hurry about it. No doubt, a single vessel, with dispatch, could be passed through the lock in less time than this.

It is only by the great initial pressure afforded by the *accumulator*, about 600lbs. on the square inch, that the valves and gates could be commanded with so much ease and rapidity. This system has been seven years in operation, and its efficiency proves the great care and skill with which all the details of construction have been wrought out. The lock was six years in building, and cost, including the enlargement of the canal, somewhere about three millions of dollars.

Besides this, there are two other locks, now called the "old locks," built by the State of Michigan, and first opened in 1855, which are still in use.

These old locks are combined, having lifts of nine feet each to overcome the whole fall of eighteen feet. The chambers are 350 feet long, 70 feet wide, and twelve feet on the sills. The gates are suspended from pillars seated on the coping of the quoins, and the chambers are filled and emptied through the gates in the old-fashioned way. The old canal and locks were assumed by the U.S. government in 1881. The registered tonnage passing through the old and new locks in 1886 amounted to upwards of four million tons, and it all passes free, both domestic and foreign. The staple articles of this commerce are, coal, copper, flour, grain, iron ore, pig and manufactured iron, lumber, salt, silver ore and building stones. Before the opening of this canal, the commerce here was nil. It had its birth in 1855, and so astonishing has been its growth that it threatens soon to exceed the capacity of both locks, in view of which the United States Government has already commenced a second enlargement, the estimated cost of which reaches nearly five millions of dollars.

This new lock is to occupy the site of the old combined locks, and is to surpass all other locks in the grandeur of its dimensions. It will have a chamber 800 feet long between the gates, the width, both in the chamber and at the gates 100 feet throughout, and the depth on the sills 21 feet. Of course there are no vessels on the upper lakes large enough to fill such a lock as this, but it is designed to pass a fleet at a

single lockage—tugs with their tow of barges and craft of all sorts. The canal is to be deepened to *twenty feet*, and the same depth of channel throughout the rivers that connect the great lakes has been adopted as the ultimate aim of the U. S. Government improvements.

SAULT STE. MARIE CANAL IN CANADA.

Canada has been slow in availing herself of her great opportunities at the Sault Ste. Marie. In 1852, I was sent there by the Government to survey for a canal on the Canadian shore, and although I found a most favorable line, and submitted plans and estimates, nothing further was done. The canal commission of 1871 recommended its construction, and yet no action was taken until last year, when the canal was surveyed by the Chief Engineer of the Department of Railways and Canals, and the works placed under contract.

There is to be one lock of eighteen feet lift to overcome the whole fall at the Rapids which varies from 17 to 18 feet or more, It is to be constructed substantially according to the one on the opposite side of the river, and will be operated by hydraulic power in the same manner but it will be somewhat longer. The chamber will be 600 ft. in length between the gates, 85 feet wide, and narrowed at the gates to 60 feet on opposite sides.

THE WELLAND CANAL AND ST. LAWRENCE NAVIGATION.

There can be no more satisfactory evidence of the prosperity of a country than the increase of the facilities for intercommunication afforded by canals and railways. Canals are put first, because it was by them that Canada first began her system of public works. The Welland, the St. Lawrence, the Ottawa, the Richelieu and the Trent were all begun before confederation, and even before the union of the Provinces of Upper and Lower Canada.

As an evidence of progress, reference may be made to the repeated enlargements of our more important works on the Welland and St. Lawrence navigation. The canals have been twice enlarged, the enlargement is in progress with the intention of providing a draft of 14 feet throughout, and steady progress has been made in deepening the channel between Montreal and Quebec, until it has now reached a depth suitable for ocean steamers, of 27½ feet at low water.

The Welland Canal, projected by the Hon. William Hamilton Merritt, was begun by a private company in 1824, and opened in 1829. It was constructed under Alfred Barrett their engineer. The locks were all of wood and their dimensions 110 ft. × 22 ft. × 8 ft. The wooden walls bulged out on either side of the chamber, and had to be hewn down from time to time to let the vessels pass.

In 1841, this work was assumed by the government, and the first enlargement was begun the same year under Samuel Power, the resident engineer. The locks were made 150′ × 26½′ × 9′ of solid stone masonry, and are in use to this day. The canal was opened in 1845, but being yet unfinished when Mr. Power resigned, it fell to my lot to carry on the works during the years 1846, 1847 and 1848, until recalled to headquarters. By raising the banks and lock walls the draft was increased to *ten* feet.

The second enlargement was begun in 1871, and completed in 1887 It was not that the volume of trade exceeded the capacity of the former enlargement, but because the locks were not large enough to pass the larger class of vessels, that, at a cheaper rate, were carrying the trade past the canal to Buffalo, and in order to cheapen traffic and secure a fair share of the Western trade, larger locks and a larger canal were absolutely necessary.

The Canal Commission, appointed in 1870 to report on the scale of navigation suitable for the canals, recommended the enlargement of the Welland and St. Lawrence Canals, for a draft of *twelve* feet, with locks 270′ × 45′ × 12′, and the enlargement was begun in 1871 on this scale; but before the work had far advanced, the Government decided the draft should be increased to *fourteen* feet, and as before stated, the Welland canal has been completed on this scale, and such of the locks as have been built on the St. Lawrence canals are of the same dimensions.

In the infancy of our Canadian trade, the most sanguine of our commercial men could scarcely have anticipated such remarkable development in the course of half a century, and yet with all our progress, it cannot be affirmed that we have reached the maximum. Even now, if the scale of navigation could be considered an open question, it is likely the length of the locks and the depth of navigation from Lake Superior to tide water would be further increased, and the number of locks reduced.

It has been suggested that some reference should be made to the first construction of the Cornwall canal, the enlargement of which is now in progress, especially to that portion of it between Moulinette and Milleroches, where the breaches have occurred, and it is my intention to do so, not in this address, but in a paper specially prepared with illustrations, to be read at one of the regular meetings of the Society. Having spent nearly six years of my younger days as assistant engineer, under I. B. Mills and Colonel Phillpotts, resident engineers in its construction, I may claim the privilege of contributing the facts in relation to the formation of the banks, that have come under my own observation.

This much, however, may be said here.

The canal and its banks were constructed of ample dimensions. The canal was 100 feet wide at bottom, and 10 feet deep. The embankment was raised to fourteen feet above canal bottom, and made twelve feet wide at top with slopes on either side of two to one.

That portion of the canal embankment on the upper reach, which for upwards of a mile in length from Moulinette to Milleroches holds the water in the canal at a level of about twenty feet above the branch of the St. Lawrence, which runs alongside, is in part founded upon the treacherous clay bottom in which were found springs of water, and in part in side cutting permeated by streaks of sand. The embankment over this ground was formed with extra care, the earth being laid on in courses with carts, and where the outer slope ran out into the river it was protected by boulder stones along its outer edge. Where springs were found under the seat of the embankment they were led out to the river's edge by French drains, and where the streaks of sand were encountered in the side cutting they were cut off by puddle trenches, six feet deep or more, and the bottom and side bank lined with puddle three feet thick from the puddle trench to high-water mark. This mode of protection was not continuous over the whole line, but was confined to such parts of the bank only as appeared to require it.

Since the opening of the canal, there have been several breaches in this bank, the last and worst of all was the breach of last fall, which inflicted such serious damage upon the trade of the St. Lawrence last year. The occurrence of these breaks from time to time, notwithstanding all the care observed in the construction of the canal, proves not only that the methods taken to secure the bank had failed, but is a clear indication that the true cause of all the trouble had not been reached and was not fully understood, and until the cause was known the proper remedy could not be applied. The event proves that springs of water or streaks of sand reached by the water have caused the banks to slide, and then to give way to the pressure from the canal.

These facts have an important bearing upon the enlargement of the existing line. The enlarged canal is to be six feet deeper than the old one. Sixteen feet of water instead of ten feet implies greater strain upon the bank, and a deeper searching after the hidden springs and streaks of sand that may be interposed between the canal bottom and the river.

In view of these facts, I do not think it possible to ensure the enlarged canal against breaches if the enlargement is confined to the line of the existing canal. What then should be done? It is not for this society to offer advice. Its functions are not executive; but all purely engineer-

ing questions directed to the advancement of the profession may properly be discussed—nothing more.

I may inform this society that in my individual capacity I have already suggested an alternative plan which will avoid the risks referred to. This plan is simply to abandon the old canal for the three miles opposite Sheek's Island, which is a Canadian island, and to throw dams across the narrow channels at the head and foot of this island to raise the water up to canal level, and form a lake three miles long, one-third of a mile wide, and 16 to 20 feet deep — substituting a lake for a canal, and leaving the old canal untouched.

The accumulated wealth of the last quarter of a century, ever seeking investment in profitable enterprises, has been employed chiefly in the development of the railway system; but of late years, interest has been awakened in canals,—ship canals of the larger class. It has been found that the smaller canals—boat and barge canals—cannot compete with railways, which are ever winning traffic from them, and will, no doubt, in the end, supersede them altogether. But this does not hold with regard to ship canals, like the Suez, the Amsterdam, the Caledonia, the Welland, the St. Lawrence, and the Sault Ste. Marie. The construction of the Liverpool and Manchester ship canal now in fair progress is an evidence of this revival, and it is remarkable to observe how nearly the great tidal lock at Eastham, where this canal leaves the Mersey, corresponds in dimensions with the lock that has been built, and the one about to be built at Sault Ste. Marie. It is 600 feet long and 80 feet wide. There are also two other locks, one 350′ × 56′, and the other 150′ × 30′. The canal is to be 120 feet wide at bottom and 26 feet deep.

RAILWAY ENGINEERING.

The history of railway construction during the last decade is pregnant with important lessons—important to capitalists, to the profession, and to the public at large. While construction is advancing with unexampled speed, the aim is still to produce ultimately a first class road, to shorten the distances by rail between objective points, to secure good alignments with easy gradients and easy curvature, as well for safety and a higher speed as for the general economy of the train service.

To save time in construction and hasten the opening of an important line, it may for a time be necessary, in remote places, to employ temporary expedients in order to establish the track in the shortest possible time, such as trestle or pile bridges, or other contrivances of the same temporary nature, but still the object is to get rid of these as soon as

possible, and finally to eliminate from the road-bed all perishable material. The engineers who have had the most experience in the maintenance of the permanent way are now deeply impressed with the supreme importance of a continuous track resting on a solid bank of earth, unbroken by wooden trestle bridges or by open beam culverts, always liable to accident from decay, from fire, or from derailment of trains. It is the existence of such temporary works, maintained too long on any line of railway, that gives rise to what are properly classed as preventable accidents. It is the part of wisdom and prudence to replace all such imperfect works as soon as possible by permanent solid embankments, and stone culverts, or iron pipes covered with clay and ballast.

Latterly it would seem as if a demand had sprung up for a higher rate of speed, both in Great Britain and the United States. Time in this advanced age, with all its hurry and bustle, has become an element more precious than silver or gold. It is the fast train that wins the traffic. To save time and distance capitalists are spending their millions on the Forth Bridge, the completion of which—expected this year—will lead to an acceleration of trains, and afford the quickest route to the north of Scotland. It is confidently expected that this line will secure the traffic and earn the dividends.

Some of the great roads, that are always kept in a high state of efficiency, and are favourable to fast running, have been testing their running powers during the past year. They have exceeded the speed of the "Flying Dutchman" on the Great Western, and the "Wild Irishman" on the Holyhead line, and the equally swift trains of the London and Brighton. On some of the better portions of these lines, on the Great Northern, and on the Pennsylvania Central, the New York Central, and one of the lines in Michigan, trains have been running from 70 to 75 miles an hour with perfect safety; but from the fact that this startling rate of speed is not continued, it is to be inferred that the public is not yet prepared for this advanced style of travel.

It is encouraging, however, to the rising engineers of our young country to find that such is the spirit of the age in which we live. With greater confidence they may now apply their highest art in the construction of our railways for the future. It must, however, be remembered that such a rate of speed as that just mentioned cannot be maintained with safety, except upon a perfect track—one that has been wisely located through a favorable country, is the best engineering line between objective points, has been constructed in the best manner, and has been consolidated by time and use. They may now revert to first principles, to the

examples set by the Stephensons, when they first projected their lines, when they cut down hills and filled in valleys in order to make the crooked places straight and the rough places smooth, spurning mere surface lines that followed the natural inequalities of the ground as we sometimes see in Canada ; they preferred going boldly through a mountain, or around it, to climbing it. Seeing that the force of gravity is constant, there must of course be a greater expenditure of mechanical power to overcome it, and no feats of engineering, be they ever so clever, can get rid of it. Still we must not lose sight of the fact that since their time a wonderful amount of courage and inventive skill have been displayed of late years in mountain climbing, particularly in Switzerland, where their engineers, being as it were to the manor born, have taken to it naturally and from necessity. By means of the endless rope or rack-railway they go directly up mountain slopes as steep as *one* in *four*. Of late, in the Hartz mountains of Germany, a happy combination of the ordinary with the rack-railway systems has been put in successful operation. The maximum gradient of 1 in 16 is provided with the rack rail, and the locomotives are arranged to work in the ordinary way on grades up to 1 in 40—the pinion and rack being put into gear when the steep inclines are to be surmounted. American engineers have likewise displayed great skill and judgment in solving the problems of mountain railways. By limiting themselves to certain maximum gradients practicable for ordinary work, and to curves of minimum radius, they have been able to overcome the difficulties of location in mountain passes by the devices of loop lines, switch backs, or zigzag lines and spiral curves, through which distance is gained to secure the ruling gradient. By such clever devices the benefits of railway service have been carried to many remote districts otherwise inaccessible and isolated. Still from the nature of things, and from the physical obstacles necessarily encountered, they cannot rank as first class railways, not being adapted for speed or heavy traffic. The decision in such cases rests between an imperfect railway or no railway at all.

In the development of the railway system, since George Stephenson, in 1829, placed the first true locomotive, the "Rocket," on the rails of the Liverpool and Manchester Railway, we may count the improvements which have been made from time to time towards the establishment of the system as we find it in our day. The ablest minds, the most skilful mechanics, have for half a century directed their attention to this noble work, and by their united efforts have produced the most wonderful system of locomotion the world has ever seen. It will be

remembered that some of the most important of these improvements are: (1) In the formation of the permanent way, there was a fight between the longitudinal and cross-bearing of the rails, which was soon decided in favor of the latter, and the cross ties (or sleepers as they are called in England) are now universally adopted. (2) The battle of the gauges was then fought out, leaving us the standard 4'. $8\frac{1}{2}$", as first employed by the Stephensons, and now generally prevalent, not so much on account of its intrinsic merits as for the reason that, being the first in the field, it had the greatest mileage when the question of the gauge had to be settled, and any departure from it meant isolation, involving the inconvenience and expense of transhipment at every break of gauge, or else providing a mixed gauge by laying down a third rail. (3) A superior class of material, viz., steel, has taken the place of iron for rails, for the tyres of driving wheels, and other parts of the locomotive, and has been largely used in bridge construction. The prestige and power of the railway system has been immensely increased by the substitution of steel rails for iron rails. The change has given great satisfaction to railway men, greater safety to travel, and greater economy in the transport of goods. Intense frost has more effect on iron than on steel, and sometimes plays havoc with iron rails. In my early experience at the first opening of the Grand Trunk, before the introduction of steel rails, we were always liable in winter to accidents from broken rails. I remember on one occasion, after a killing frost by night, followed by bright sunshine the next morning, no less than thirteen rails were broken between Brockville and Montreal, and a new Birkenhead with leading wheels did it. It was the bridge, or U rail, that was most liable to breakage, for the reason, as I imagined, that the hollow seat of the rail kept it cold, while the sun's action on the top warmed and expanded the top-bearing surface, and so the opposing forces of cold and heat weakened the rail. Since the introduction of steel rails we rarely hear of a broken one.

It is not often that the best material is likewise found to be the cheapest, and it is well for those who travel that steel rails are not only more durable and safer than iron rails but they are also cheaper. During the past year they were sold f.o.b. in England as low as £4 per ton. The enormous capacity of production of modern steel works both in Great Britain and in the United States must tend to keep down prices. It is the actual cost of production, which in the long run must be the basis of price. In the case of steel it has continued to fall, while in iron-making the troublesome intermediate process of puddling hinders reduction below a certain point.

(4) The automatic air brake of Westinghouse has proved a great boon to the railway service. By affording more perfect control of trains in motion it has been the means of averting many accidents, and consequently has been very generally adopted on the passenger trains of all first class roads. If the Railway companies could see their way to adapting the same system continuously to the freight trains instead of the hand brakes now in use, there would be greater security for life and property; and if the brakesmen were not exposed to the danger of walking on the tops of the cars, the height of tunnels and overtrack bridges might be made seven feet less, thereby much reducing the cost of construction.

Another desideratum is the want of uniformity in the construction of freight cars, but especially the want of a uniform car coupler. Going through any of the yards of the Grand Trunk Railway, or any other railway in Canada, there may be seen many different kinds of cars from all parts of the United States and Canada, all mixed up in the same freight train. The coupling of this promiscuous lot of cars becomes a dangerous operation for the servants of the company. In the 160,000 miles of railways on this continent, this same dangerous operation is going on daily and nightly, with frequent loss of life or limb. To avert this, railway men have long earnestly desired to find a remedy. They have exercised their inventive genius in devising self-acting car couplers, and in the patent offices may be seen any number of them; but it is obvious that until the cars are of uniform construction so that their buffers shall meet fairly, and the coupling be always at the same height over the rails, and fairly in the axis of the railway they cannot, if ever so well designed, be generally adopted so long as they have such a variety of rolling stock to provide for.

It has often occurred to me that an effectual remedy to this state of things might be provided by the united efforts of the Railway Companies in Canada and the United States. Let all the great leading companies send delegates to an international convention to meet at some convenient and central place. The convention should be composed of skilled mechanics, mechanical superintendents and railway managers, whose duty it should be to investigate the question, and report on the best means of protecting the brakesmen and car couplers from the dangers incident to their calling. And should this international convention unite in suggesting a practical remedy, one that meets the general approval of the companies, the sanction of legislative authority might then be given it by both countries. Such legislation would be an act of humanity worthy of two christian nations whose interests in this matter are identical.

THE FORTH BRIDGE.

This stupendous structure, begun in 1883, is gradually but surely approaching completion, and will probably be opened for traffic next autumn. This design of the engineers—Sir John Fowler and Mr. Benjamin Baker, under whose personal directions the works have been carried on—has been so fully described in the engineering newspapers, and the progress of the work so faithfully reported from time to time—that it is unnecessary to enter into these details; but the length of time, six years—occupied in its construction, and the large force employed, sometimes numbering more than four thousand men, furnish the best idea of its great magnitude. The bold conception of such a work as this, and the skill and ability shown in carrying it out, to me is most surprising and most admirable. The profession has been struggling for years to devise a great span bridge that shall be rigid and suitable for railway traffic, but has never been able to get much beyond a span of 500 feet. Suspension bridges, it is true, might be extended to three or four times that span, but they can never be stiffened sufficiently for the safe passage of trains at speed, and are therefore unsuitable for ordinary railway service. But in the Forth Bridge, the engineers have *per saltum* carried the practical span from 500 to 1700 feet, and there are two spans of this length. The towers rise to a height of 340 feet over high water, and the headway under the bridge is 150 feet. The depth of water between the piers is 200 feet. The steel employed in its construction amounts to 52,000 tons.

In ancient times the Colossus of Rhodes was counted one of the wonders of the world. It is a mere pigmy compared to this colossus of bridges. This brass statue of Apollo stood 130 feet high, and weighed 321 tons. If floated erect upon a barge it would pass as easily under the Forth Bridge as the steamers of the St. Lawrence pass under the Victoria Bridge here in Montreal.

THE CANADIAN PACIFIC RAILWAY.

So much has been written of late on the subject of the Canadian Pacific Railway—it has been so well described—and such great *kudos* awarded to the company for its enterprise and courage, its energy and perseverance in the prosecution of this great national railway, that it would seem as if the subject were exhausted, and there was nothing more to be said. Still there is room for a few remarks in reference to the present location of the line through the Rocky Mountains. There are certain defects on this portion, described by competent engineers, arising from hasty construction, and the necessity of opening the

railway for traffic with the least possible delay, which limit the speed and capacity of trains over nine of the one hundred and thirty-four miles which embrace all the grades exceeding one per cent. through the Rockies and Selkirks. The maximum ruling grade throughout the line east and west of these ranges is one per cent., whereas for six miles in the Kicking Horse Pass the grade is four and one half per cent. To protect the track on the flanks of the Selkirk range, and in the Eagle Pass of the Gold range, against snowslides and avalanches, about seven miles of heavy timber snowsheds have been constructed. Some of these form an artificial tunnel over the track, and are built of solid timber crib work at great cost. In order to protect these against fire, a complete system of fire protection afforded by abundant streams from the mountain sides has been established.

It cannot be supposed that our transcontinental highway can long be placed at a disadvantage by impediments to its traffic such as these just mentioned, especially if the through trade to the East ever reaches the important proportions expected of it. In its present condition the line will serve to develop the traffic, and when increased facilities are needed, there is no doubt that the resources of engineering skill will be adequate to provide them. This view of the case seems to have been recognized by the Company when they referred to a "temporary line" in their location through the Rockies.

To civil engineers generally, but especially to the mechanical superintendents of motive power, it will be a matter of interest to know what classes of locomotive engines are doing the work on the main lines in Canada. As regards those of the Canadian Pacific, the principal dimensions of the more powerful passenger and freight engines in use in the mountain sections of British Columbia are given in the address of the President of the American Society of Civil Engineers, of the 28th June last, and published in their transactions, and therefore need not be repeated here. The characteristics of the Standard engines employed on the line *east* of the Rocky Mountains have been kindly furnished me by Mr. Brown, the Mechanical Superintendent, as follows:

PRINCIPAL DIMENSIONS OF STANDARD PASSENGER ENGINE.

Cylinders and Motion.

Cylinders, type	Half saddle
Cylinders, diameter by stroke	19″ × 22″
" distance apart of centres	6′ 5″
Steam Ports, length by width	18″ × 1⅝″
Exhaust " " "	18″ × 3¼″

Diam. of piston rod ..... $3\frac{1}{4}$"
Piston head, type..... Solid with C. I. rings
" rod, material.....Mild steel
Length of connecting rod.....7'.8"
Connecting rod, material.....Mild steel
" journal, main length and diam.....5" × $4\frac{1}{2}$"
Travel of valve..... $5\frac{1}{2}$"
Throw of eccentries ..... $5\frac{1}{2}$"
Lap of valve..... $\frac{1}{16}$"
Crosshead type.....Open bars
" material .....Cast steel
Packing for piston rods and valve stems.....U. S. metallic

Wheels and Frames.

Driving wheels, diam.....5'.9"
" " tyres, width by thickness.....$5\frac{1}{2}$" × 3"
" axle journals, diar. and length.....8" × 9"
" " material.....Mild steel
Truck " " ..... "
" " journals, diar. and length.....5" × 8"
" wheels, diar Krupp's coiled disc centre "..... .....36"
" " tyres, width by thickness.....5" × $2\frac{1}{2}$"
" " base .....6'. 3"
Fixed " " .....8'. 9"
Total wheel base of engine .....23'. $6\frac{1}{4}$"
Thickness of frames.....$3\frac{1}{4}$"
Width over " .....4'. $2\frac{1}{4}$"
" between tyres.....4'. $5\frac{1}{2}$"
Centre of cylinder to centre of driving axle..... .....11'. 8"
Spring gear.....Under hung

Boiler.

Type..... Wagon top and deep fire box
Length of barrel.....11'. $0\frac{3}{4}$"
Diam. " outside. .....4'. 6"
Thickness of plates.....$\frac{7}{16}$-in
" " tube plates.. ..... $\frac{1}{2}$"
Fire box, length inside..... 6'. $3\frac{1}{16}$"
" width " bottom and top.....2'. 11" and 3'. 9"
" length outside.....7'. 0"
" width outside bottom.....3'. $6\frac{1}{2}$"

Fire Box depth inside .....6′. 4¾″
Tubes, No. and diam. outside.....204, 2″
" length between tube plates..... 11′. 4¾″
" heating surface in fire-box.....1235. sq. ft.
" " " .....134.3 "

Total " " .....1369.3 "

Grate area ..... 18.4 "

Weight in working order on truck.....32,500 lbs.
" " " on drivers.....66,500 "

" total.....99,000 "
" of tender empty.....33,000 "
Capacity of " coal.....10 tons
" " water.....2800 gals. Impl.
Boiler pressure.....160 lbs.

PRINCIPAL DIMENSIONS OF STANDARD MOGUL FREIGHT ENGINE.

Cylinders and Motion.

Cylinders, type.....Half saddle
" diam. and stroke.....18″ × 24″
" distance apart of centres.....6′. 11″
Steam ports, length and width.....17″ × 1½″
Exhaust " " " .....17″ × 3″
Diam. of piston rod.....3¼″
Piston head, type.....Solid, with C. I. rings
" rod material.....Mild steel
Connecting rod, length.....7′ 8″
" " material.....Mild steel
" " journal, length and diam.....5″ × 4½″
Travel of valve.....5⅝″
Throw of eccentries.....5½″
Lap of valve.....⅞″
Cross head type.....Laird
" material.....Cast steel
Packing for piston rods and valve stems.....U. S. Metallic

Wheels and Frames.

Driving wheels diam.	4′. 9″
" " tyres, width × thickness	main driving 6″ × 3″ bald
" " " " " L. and T.	5½″ × 3″ flanged
" axle journals, diam. × length	7″ × 8″
" " material	Mild steel
Truck " "	"
" " journals, diam. × length	5 × 8
" wheels, diam "C. I. Special-Ground and balanced."	2′. 6″
Fixed wheel base	14′. 6″
Total " " of engine	21′. 11½″
Thickness of frames	3¼″
Width over frames	4′. 2¼″
Type of frames	Double bar
Width between tyres	4′. 5½″
Centre of cylinder to centre of driving axle	11′. 10½″

Boiler.

Type	Wagon top, shallow fire box over frame.
Length of barrel	11′. 4¾″
Diam. " outside	4′. 6″
Thickness of plates	½″
" tube plates	½″
Fire box, length inside	8′. 0½″
" width " bottom and top	3′. 6¼″
" length outside	8′. 9″
" width " bottom	4′ 2¼″
" depth inside, front and back	4′ 9″ and 3′. 6½″
Tubes No. and diam. outside	208, 2″
" length between tube plates	11′ 8⅛″
" heating surface	1277.3 sq. ft.
Fire box "	110.6 "
Total	1387.9 "
Grate area	28.7 "
Weight in working order, on truck	13,000 lbs.
" " " on drivers	86,000 lbs.
" total	99,000 lbs.
" of tender empty	33,000 lbs
Capacity " coal	10 tons

Capacity of, water.....2800 gals. Impl.
Boiler pressure. .....180 lbs.

THE GRAND TRUNK RAILWAY.

I have always entertained a special regard for the oldest of our main lines of railway, because in 1852 I left the Government service to take part in its construction under Alexander Mackenzie Ross the chief engineer. It was for the Government of that day that I made the location of the present line (then called the front line) between Kingston and Montreal, and it was on that location that the Grand Trunk Company undertook to build it. I remained in the service of the company until it was completed and opened for traffic.

A very important work, in which this company is now engaged, is the doubling of their line of 333 miles between Montreal and Toronto, for which provision was made in the permanent abutments of the larger bridges at the first construction of the railway, more than thirty years ago. At the close of last year about one third of this distance had been doubled, the curves eased, and the heavier grades reduced. The portion which I located for the Government between Montreal and Kingston was designed for maximum gradients of 1 in 200 going East, in the line of the heaviest traffic, and 1 in 100 going West; but afterwards, the grades both ways were made the same 1 in 100. The company is now coming back to the original design.

The doubling of the line was not begun one day too soon. Already they find the greatest benefit from the several sections now completed in the increased facilities for crossing trains. Trains that any hour in the day might be seen pocketed in the sidings all along the line, awaiting orders to proceed, are now set free, and the capacity of the line for the despatch of business greatly increased; when the whole line is doubled, the rolling stock can be much more profitably employed.

Another important work is the tunnel under the St. Clair River at Sarnia, to make a more complete connection between the Chicago and Grand Trunk in Michigan, and the Great Western branch of the Grand Trunk in Ontario. It will require three miles of line to make this connection, one mile of which will be a tunnel, and half of that mile will be under the bed of the river. The Company has already spent about $100,000 in driving an experimental heading to test the material through which it has to be made. To make sure work of it, the plan is to use shields, one sunk to grade at either portal, and both pushed forward by hydraulic presses until they meet in the middle. The shields to be twenty feet in diameter, each worked by eighteen hydraulic presses.

The work is conducted under Mr. Hobson, M. Can. Soc. C. E., and Chief Engineer of the Great Western division. The shields and machinery are all prepared, the lighting of the works by electricity, the ventilation and pumping provided for, and everything ready to begin work.

LOCOMOTIVE ENGINES.

By special request I have been kindly favored by Mr. Herbert Wallis, Mechanical Superintendent of the Grand Trunk Ry., with the following particulars, giving the principal dimensions of the Standard Passenger, Freight and Shunting engines now in use on the line.

The Standard Passenger engines have cylinders 18" × 24" and four coupled driving wheels, 5' 8" diameter. Tractive force at rail for each lb. effective pressure 114½ lbs., weight in working order (ex-tender) 97,000, lbs. of which 60,000 lbs. is on the driving wheels. Grate area 17¾ sq. feet. Heating surface 1304 feet of which 120 feet is in fire-box. Boiler is made of ½ inch steel plates, butt-jointed with strips both inside and outside and double-riveted, the fire-box being of steel. The boiler carries 150 lbs. pressure, and is covered with silicate slagwool woven into a matting, so that it can be readily removed. The smoke-box is extended forward, a high exhaust pipe, with netting below the orifice, is used, thus dispensing with the cone and diamond stack, regulating the draught, preventing the emission of sparks, and reducing the quantity of fuel consumed and the wear and tear on the fire box and tubes. Outside connecting rods are of I section, and are made with solid ends and brass bushes. Fire-box crown sheets are stayed to the boiler by "through" stays, screwed at both ends, and riveted over, but recent experience tends towards the use of several transverse crown bars on the front of the box, to better provide for the upward thrust of the fire-box without injury to the shell. The main valves are of cast iron, and are balanced in such a way as to prevent undue friction in working; the motion is of the usual lifting link type.

The Standard Freight engine has six coupled wheels with a single pair of radial wheels in front. The cylinders are 18" × 26", and the driving wheels 5' 2" diam., the truck wheels being 3" 1' diam., pressure of steam 160 lbs. Weight total 99,000 lbs., of which 84,000 lbs. is on the driving wheels. Tractive force at rail for each lb. effective pressure 136 lbs. Heating surface 1232 sq. feet, of which 117 ft. are in fire-box. Grate surface 17.66 sq. feet. The general remarks as for passenger engines apply, except that the side rods are of the strap and brass type. The passenger engines are equipped with Westinghouse Automatic Air Brakes, all classes having their valves lubricated with "sight

feed " lubricators, and their glands (piston, spindle, etc.,) packed with metallic packing.

The Standard Shunting engine has cylinders of 18" × 22" with three pairs of driving wheels coupled, of 4' 9" diam., and is without truck. It has a steam brake in charge of the engineman ; water is carried on the foot plate in tanks, there being no independent tender, and weighs 114,000 lbs., including 1860 imp. gallons of water and 6,000 lbs coal. Tractive force as before 125 lbs., boiler pressure 140 lbs. Heating surface 1002 sq. feet, of which 95ft. are in fire-box. Grate area 16½ sq. feet, outside rods same type as standard freight engine but general details otherwise similar. Neither freight engines nor shunters carry Westinghouse Brakes.

ELECTRICAL ENGINEERING.

ELECTRIC TRAMWAYS. Considerable progress has been made in America within the last three or four years, in the application of electricity as a motive power to street cars. The system is yet in its infancy, and there are several different modes of its application, but many able and practical minds are engaged in the solution of the problem. So far, however, there has been a continual advance, although as yet none of the systems heretofore contrived are free from defects. In a report on this subject, dated 18th January, 1888, prepared by Captain Eugène Griffin, for the U. S. government (and kindly lent me by Mr. E. A. Smith, President of the Electric Tramway, St. Catharines and Thorold), a detailed description of the systems now in use is given. They are the Van Depoele and the Daft systems, taken as examples of the air-line methods—the Bentley-Knight and the Short-Nesmith as examples of the conduit methods, and the storage battery or accumulator system in which the motive force is self-contained and no conducting wires are needed. A list is given of nineteen tramways, overhead conductors, now in operation, varying from one and a half to twelve miles in length, two of which are in Canada, St. Catharines and Thorold, 6 miles, and Windsor and Walkerville, one and a half miles, both on the Van Depoele system. These lines had to overcome many difficulties and drawbacks incidental to the starting of a new system, and are now in successful operation. There is but one line with underground conductors, four miles in length, Bentley-Knight system, at Denver, Colorado. Then there are under contract and in course of construction 22 lines, and of lines projected 54 more.

Captain Griffin, having devoted much attention to the subject, reported

that "electricity as a motive power, in comparison with animal traction, offers many advantages, to wit, more rapid transit and better service, cleaner streets, smoother pavements between tracks and rails, less noise, less obstructions on crowded streets, less liability to accident, as the cars can be stopped more speedily, and if needful, the movement be reversed, fewer repairs on tracks and pavements, the abolition of stables, and diminished cost of maintenance and operating expenses."

It is admitted that the first cost of electric plant may be double that of the horse tramway, but it is claimed that the annual running expenses, including interest on first cost, are less. He gives an estimate of the cost of construction and equipment for ten miles of horse, cable and electric tramways, as follows:

Electric tramway	$404,000
Horse tramway	202,000
Cable tramway	566,500

Annual running expenses, including 6 per cent. interest on first cost.

Electric tramway	$ 50,311
Horse tramway	106,820
Cable tramway	85,058

The electric tramways may be well suited for more southern and temperate climates, where the track can be easily kept free from snow in winter, but it cannot be expected that they will be generally applicable to the more rigorous climate of Canada. It must be observed that the two lines at present in operation in Canada occupy the extreme southern portion of it between the great lakes, about latitude 42°, and it is reported by the President of the St. Catharines and Thorold line, that the only difficulty they experience is when a storm of sleet coats the conducting wires with ice, and renders the insulation inoperative until it is removed.

It is to be observed that all the lines in use are short suburban lines, averaging about five miles in length, the longest as before stated twelve miles. This system now in process of development may, in a few years hence, be very much improved and more widely extended. In some parts of our Northwest, where there is but a light fall of snow, and where cattle remain out all winter, the towns expecting to become cities may yet find the electric tramway the best suited for their wants.

ATLANTIC AND PACIFIC CABLES. Submarine electric telegraphy, lighting and motive power are all so closely associated with Civil Engineering, that Electrical Engineering is now one of the most important and progressive branches of our profession.

In connection therewith, it is of interest to note that the Imperial and Colonial Governments are taking active measures for the establish

ment of direct telegraphic connection between Great Britain and her Australian Possessions, *via* Canada.

Also that the Canadian Government purpose completing their admirable Gulf of St. Lawrence Service, by connecting their North shore land line and their Anticosti Cable and land line systems by cables to Greenly Island, Straits of Belle Isle.

In connection with the latter auxiliary assistance, private capitalists have determined that Canada shall have a cable from Greenly Island to the West Coast of Ireland or Scotland, and thus complete transatlantic communication under the direct control of the people and government of Great Britain and her Colonies.

SANITARY ENGINEERING.

The protection of the public health in our cities and towns is usually committed to the Board of Health and to the City Engineer as the executive officer. Sanitary reforms have occupied the attention of leading medical and engineering authorities in Europe for many years, especially in England where the density of the population renders them more necessary. Science has done much of late years for the health and well being of the dwellers in cities and towns—saving annually many thousands of lives, wherever its teaching has been intelligently regarded; and much more might still be accomplished in the same direction if the people generally were more alive to the great importance of the subject.

It has now come to be pretty well understood as an established fact in sanitary science, that imperfect drainage of houses, badly constructed sewers, polluted drinking water, and filthy streets, are direct causes of disease and death, as to the same causes, scarlet fever, measles, diphtheria, typhus and typhoid fevers may be referred.

In the city of London, two centuries ago, the mortality was 80 per 1000, and it was not until the beginning of the present century that the birth rate exceeded the death rate. According to the "Bills of Mortality" there has been a steady decline in the death rate ever since, until now by a more strict attention to sanitation, London has become one of the healthiest cities in the world.

Mr. Edwin Chadwick, a leader of sanitary reforms in England, has lately stated in Brighton, that it is not long since the death rate of London was 24 per 1000, and now it is but 14 or 15 per 1000; and he maintained that had the sanitary reforms been carried out

according to the plans prepared, it might have been reduced to 12 per 1000. Referring to special classes he said the death rate in the Guards, a quarter of a century ago, was 20 in 1000; it is now 6½ in 1000. In Germany the results are even better, the army death rate being from 5 to 6 per 1000. He states that in the large school districts of the Poor Law Unions, the chief diseases of children—measles, whooping-cough, typhus, scarlatina, and diphtheria—are "practically abolished."

It is to be deplored that we have no such progress, no corresponding results, to point to in Canada.

About a year ago there was published in the *Montreal Star* (14 Jan., 1888) a list of twenty towns and cities in Canada, shewing the populations and deaths, and the death rate per 1000. These twenty towns and cities had then an aggregate population of 653,047—the deaths 16,586, and the average death rate 25·40 per 1000.

As we have no "Bills of Mortality," nor any vital statistics with which to compare these figures, it will be sufficient for my present purpose to assume them as approximately correct at the time they were made.

Then comparing the twenty modern towns and cities enumerated, with the ancient historical and densely populated city of London, in which there are as many people now living as there are in all Canada, it might reasonably be expected that the mortality in these Canadian localities could, by strict sanitation, be reduced to a par with that of London, in which case fully six thousand lives might annually be saved to the country in these places alone. But when we take these several places in detail we find some startling revelations. The lowest rate of mortality is found in the inland towns and cities of Ontario. These towns are Belleville, Guelph, Chatham, Galt, Peterborough, ranging from 16·50 to 19.75 per 1000. The cities are London, Kingston, Hamilton, Toronto, ranging from 18·31 to 21·50 per 1000. Halifax shews 20·52, Ottawa 28·70, Montreal 27·99, Quebec 33.57, Three Rivers 32·10, Sherbrooke 27·37, St. Hyacinthe 41·83, and, saddest of all, Sorel 44·88 per 1000!

There is cause for serious reflection in these figures, shewing what a heavy responsibility rests with the Boards of Health in all larger cities and towns. I have gone into these details in order to prove to the Sanitary Engineer that there is in Canada plenty of important work for him to do.

There is no branch of the engineering profession in which a man can do more good to his fellow man than in protecting and promoting the health and comfort of those who have their homes in towns and cities

where he can apply his beneficent art to save life, and preserve the health of the living. It will be his pleasing duty to provide pure water, pure air, clean streets, and a perfect system of drainage, that shall carry off all surface water before it has time to become stagnant, and all waste from houses and yards before noxious gases are allowed to generate, and to convey the same with all possible dispatch to the proper outfall, there to be disposed of as circumstances shall dictate.

FAILURE OF THE SUSPENSION BRIDGE AT NIAGARA FALLS.

The members of this Society will be glad I am sure to be informed of the circumstances connected with the recent failure of the Suspension Bridge at Niagara Falls, which I constructed for the Bridge Companies, and which was opened for traffic on the 4th January, 1869, just twenty years ago. All the particulars relative to the first construction of this bridge were published in a report made by me to the Directors, dated 1st March, 1869, and this report with illustrations was the same year given in "Engineering," in England.

The span of this bridge is 1268 feet between the points of suspension at the towers. The roadway was 10 feet wide, providing a single track for carriages, and a path for foot passengers. The roadway was supported by two cables, each cable composed of seven wire ropes, each rope of seven strands, each strand of nineteen wires 0·155 inch in diameter, No. 9, B.W. G. Each rope had a guaranteed tensile strength of 100 gross tons=112 tons net. They bore the test of 108 tons net without rupture of the rope, when the fastenings gave way.

The single track bridge was designed to carry with perfect safety a load of 100 tons without producing a strain of more than twenty-five per cent. of the ultimate strength. Besides the cables there are over-floor stays which are a real support to the roadway; and in order to keep the roadway from swaying about in the wind, there were 54 guys, 28 of which were on the up stream, and 26 on the down stream side. Some months after the bridge was opened there was added both on the up stream and down stream side a horizontal arched cable, with horizontal stays between them and the roadway, which had a good effect in steadying the bridge.

The original bridge rested on wooden towers, but for fear of accidents by fire the Directors substituted steel towers for wood.

About two years ago the Directors decided to make the bridge a double track bridge without consulting me in the matter. They proceeded to take down my single track roadway, and to substitute a double track. This enlargement was completed in September last. I have not seen any of their work, and from lack of information I am unable to state what

means were adopted by them to secure the double track against the additional strains that must come upon it—the additional strain on the cables and stays, and the additional surface offered to the force of the wind, for which more guys would have to be provided.

My bridge, before it was opened to the public, was officially inspected by officers of the Dominion, and of the State of New York; the Directors also employed the Hon. W. I. McAlpine, their consulting engineer, to report more fully in regard to its sufficiency.

My bridge weathered the storms for twenty years. My cables and anchorages are still in place, and, I understand, are to be used in the reconstruction of the bridge. My roadway was not blown from the cables, it was taken down by the Bridge Company. It was the double track roadway substituted for the single track that was blown away only three months after it was put up; and I am not aware that there was any Government inspection of it

It is a fortunate circumstance that no lives were lost in this accident. From all accounts it was a terrible storm. The anemometer at Buffalo registered the velocity of the wind 88 miles an hour.

The great problem to be solved in the construction of a bridge over this chasm is to keep it from being injuriously affected by wind storms which not only cause vibrations like that of a pendulum, but wavelike undulations throughout the length of the roadway and the suspended portion of the cables. To guard against these a cradle form is given to the cable, and the over-floor stays from the towers to the roadway, as well as the cradle stays from the cables to the base of the towers, serve to check these undulations, while the under-floor guys reaching down at various angles from the roadway to the rocks along the river bank, meet and check the lateral force of the wind upon the whole suspended system.

To balance these forces one against the other, and leave a fair margin for safety, will tax the best skill of the engineer, because the storms through this gorge seem to drive with greater fury in consequence of its funnel shape.

An opinion was expressed by the late J. A. Roebling, who built the Railway suspension below this, that no bridge could be made to stand here at the falls; not on account of the storms, but from the spray coming from the American Fall, which would cover the bridge with ice and break it down. But the experience of twenty years has proved there is no danger to be apprehended from this cause. In deference however to his opinion, the bridge was made a tentative structure, so that, if successful, it might afterwards be enlarged and made a permanent structure.

CIVIL ENGINEERS OF CANADA.

The time has come when the younger engineers of this Society would like to know who were the engineers that projected and carried on the public works of Canada, from the earliest times down to the incorporation of the Society, and upon what works they were employed. Their names should not be lost to history.

As all, or nearly all, of these engineers have, at one time or another been employed in the service of the Government, it was necessary to refer to the public departments for the information required—the Department of Public Works and the Department of Railways and Canals. In my efforts in this direction, I was so fortunate as to find a member of this Society, Mr. G. F. Baillairgé, the Deputy Minister of Public Works, quite willing, not only to meet my wishes, but ready to undertake, on his own account for his Department, the preparation of the roll of engineers employed on the public works of Canada from 1815 to 1889, which will be published as an appendix to the annual report of his Department. From his length of service in the Department and his intimate knowledge of every detail connected with it, there is no one better fitted to supply the information than Mr. Baillairgé. He has already completed the list, and furnished me with a few advance copies, one of which is now presented. The official information thus supplied is a valuable contribution to Canadian history, and should satisfy all the parties concerned. Errors and omissions, if any, can be corrected in the next edition, if sent in proper time to the Department.

I had hoped to receive similar information from the co-ordinate department of Railways and Canals, but as yet it has not been supplied.

In conclusion, I cannot but refer with much pleasure and satisfaction to the opening of the List of Honorary Members.

The election of His Excellency, the Right Honorable Lord Stanley of Preston, Governor General of Canada, who, amidst the distractions incident to an active political life, has found time to take an interest in the profession of the engineer, and of Sir William Dawson, F. R. S., whose scientific attainments are too well known to need any comment from me, must add lustre to "our young but vigorous Society."

Thursday, 31st January.

P. A. PETERSON, Vice-President, in the Chair.

Paper, No. 27.

CANTILEVER BRIDGES.

By C. F. Findlay, M.A., A.M. Inst. C.E.

A structure which is supported at one end of its length only, so that it requires for equilibrium the application of other forces than those applied at the support, is commonly called a cantilever. If such a structure forms part of a bridge the bridge may be called a cantilever bridge. This description agrees sufficiently well with the ordinary usage of these terms, and any attempt at rigid definition would serve no good purpose.

It is sometimes maintained that a cantilever bridge should be regarded and treated simply as a continuous-girder bridge, in which the points of contrary flexure are arbitrarily and permanently fixed by cutting the booms; but this point of view would exclude all cantilever bridges which are anchored at the abutments instead of being continuous with a neighboring span, and also it is both illogical and misleading to classify as a variety of continuous girders those in which the most prominent feature is the breach of continuity at certain points.

The cantilever is in regard to the distribution of stress in it one of the simplest of framed structures, and no one who is familiar with the analysis of stresses in ordinary bridge and roof trusses, will find any difficulty in calculating the stresses in a cantilever bridge from given drawings and loads, difficulty, that is to say, inherent in the cantilever system.

There are, however, several features peculiar to the cantilever which deserve attention in regard to *design*, and to these we shall confine our attention, taking it for granted that those points which the cantilever has in common with other bridges are familiar to our readers.

The manner in which the cantilever is employed to form part of a bridge varies very much from one bridge to another. In some cases two similar cantilevers spring from neighbouring abutments in opposite directions, so that one forms a counterbalance to the other except as regards moving loads. In other cases, a cantilever stands alone and is kept in equilibrium by guys or backstays connected to an anchorage. Sometimes an opening is spanned by two cantilevers with a central span resting on their ends, and sometimes by one cantilever with an independent span from its end to the other abutment.

Examples of these various types of cantilevers are shewn in the accompanying diagrams, Plate III of which Fig. 1 represents the bridge now in course of construction over the Forth near Edinburgh in Scotland; Fig. 2 represents a bridge being built over the Indus river in India; Fig. 3 represents the Jubilee bridge crossing the Hooghly river near Calcutta in India; Fig. 4 represents the bridge over the St. Lawrence below the Falls of Niagara. The great difference between the parts played by the cantilever in these different designs, is mainly accounted for by the character of the sites of the bridges.

The reasons that may lead to the adoption of the cantilever-bridge in preference to any other type for certain situations are two:—

First, where the span is very great, the cantilever bridge generally requires less material than any other rigid structure of equal strength, even though anchorage may have to be provided. Where two large spans have to be built, a double cantilever requiring no anchorage, may effect a very considerable saving in material, though it must not be forgotten that in this case, a double pier of sufficient width for stability under all conditions of loading is necessary.

Secondly, where false works would be impossible or costly, the valuable property of the cantilever, that it can be made to suppport itself during erection, gives it an immense advantage. If the design of the cantilever be such that it can be built out rapidly and cheaply, it will often be the most economical form in the end, even where its total quantity of material is not so small as that required by some other type of bridge. In all engineering work quantity of material is only one of the elements of cost, and it is of the greatest importance to bear this in mind in designing a cantilever bridge, because a want of regard to the method of erection, may easily add to its cost an amount much greater than can be saved by economising material.

The principal points which arise for consideration at the outset, in commencing to design a cantilever bridge are these:

(1) The depth to be given to the cantilever at the abutment;

(2) The outline the structure is to have in elevation, or, in other words, the rate at which the depth is to vary in passing from the abutment to the outer end of the cantilever;

(3) The length of the panels into which the cantilever is to be divided by the bracing, and whether this length is to be uniform or not;

(4) The length of the cantilever in relation to the entire span.

The first three of these points are intimately connected with one another, and none of them can be settled by a mathematical investigation applicable to all circumstances.

The theoretical investigations which have been made on questions of this character are all vitiated (as regards their application to cantilevers) by the assumption that the load on the bridge is uniform throughout its length. This assumption is nearly enough correct for ordinary truss bridges, because the web is heavier where the booms are lighter, and so the weight of the truss is distributed along its length with an approach to uniformity, and also because for all ordinary spans the weight of the girders is considerably less than that of the floor and the moving load together, so that a small variation in the load per foot due to the main girders is of less importance. With a cantilever, however, especially when used (as it generally is) for large spans, the case is entirely different. The web and booms are both heaviest at the abutment and diminished simultaneously on travelling away from the abutment. Also the weight per foot of the main framework of the cantilever, where greatest, will in a large span be generally much greater than that from all other causes. When it is also considered that the cantilever as a rule, has to carry a heavy concentrated load on its end, it is obvious that all general conclusions founded on an assumption of uniform weight must be fallacious.

As an illustration, it may be mentioned that the cantilevers of the Indus Bridge (Fig. 2) weigh about 1 ton per foot at their outer ends, and about 6½ tons per foot at the abutments (apart from the uniform load of the floor which is about ½ ton per foot), and they are designed to carry a concentrated load of 300 tons at the end.

In observing the important effect of this concentrated load on the cantilever we see how misleading it might be to regard the entire span as one continuous girder bridge with fixed points of contrary flexure, because that point of view masks the fact that when the continuity is destroyed the central part is just as much an independent span as if it rested on stone piers. Whatever proportions would lead to the greatest economy in an independent span of the same length should *a fortiori* be adopted for the central span of a cantilever bridge, because any extravagance in the central span has to be paid for over again in extra weight in the cantilevers. Half the benefit of destroying the continuity is lost, if we do not take advantage of it to design each part of the bridge in the way most suitable for that part. In a comparison of the weights of girder bridges with those of cantilever bridges, the concentration of weight near the abutments in the latter is an immense advantage on their side.

The marked effect of taking into account the varying weight of the cantilever is very well seen, if the theoretical case be considered in which

the web members consist only of vertical posts or suspenders. For a load uniformly distributed horizontally, we know that the curve of a suspension cable, of an arched rib or of the boom of a bow string girder, must be a parabola that no diagonal bracing may be necessary. These constructions are, each of them, as far as the stresses go, analogous to the cantilever without diagonal bracing, and we shall see that if the varying distribution of the load, owing to the varying depth of the structure, be taken into account, the parabola becomes approximately an ellipse. So long as the span is short, the ellipse and parabola would nearly coincide, but for a large span the difference would be considerable.

In Figs. 5 and 6, let A be the abutment ;

" L a be the length of a cantilever in feet ;

" L tons be the load at the end from an independent span resting on it.

Let O be the origin of coordinates, and one boom OX being horizontal, let x, y be the coordinates of any point P in the other boom.

Fig. 5.

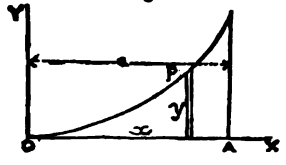
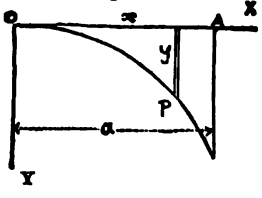


Fig. 6.



Let S be shearing force at P in tons.

" M be bending moment at P in foot-tons.

" w be total weight per ft. in tons carried by the cantilever, at P (w varying with x)

" K be such a factor, that if T tons be the stress on any member of the cantilever and 1 ft. its length, its weight is KTl tons, and assume K to be constant. (For steel with the stress usually allowed, and allowing for loss of section or increase of weight at connections K is about ·0003.)

$$\therefore \quad dM = S\,dx$$

$$\text{and } dS = w\,dx$$

$$\text{whence} \quad \frac{d^2M}{dx^2} = \frac{dS}{dx} = w$$

As it is assumed that there are no diagonal stresses, the stress in the horizontal boom is constant and = (say) H.

$$\therefore \quad M = y\,H$$

$$\text{(1)} \qquad \text{Hence } H\frac{d^2y}{dx^2} = w.$$

Now w consists of two parts:—the uniform load per foot carried by the cantilever (including all parts of the bridge, such as flooring, etc., which are approximately uniform), and the variable weight of the web members and booms.

Let the constant part of $w = m$.

The weight of horizontal boom for horizontal distance $dx = KH\,dx$

" of curved " " " $dx = KH\left(\frac{ds}{dx}\right)^2 dx$

" of vertical suspenders or posts $= Kwy\,dx$

[The last expression is not strictly correct, as the weight of the curved boom is not transmitted through the verticals, which do not therefore carry the whole of w. The error here made would, however, in practice, tend to counterbalance other incorrect assumptions, for it becomes more serious as the abutment is approached, and at the same time the secondary bracing and wind bracing, which have been supposed uniformly distributed, must in practice become heavier.]

We have then $w = m + K\left\{ H + H\left(\frac{ds}{dx}\right)^2 + wy \right\}$

whence by (1).

$$H\frac{d^2y}{dx^2} = m + K\left\{ H + H\left(\frac{ds}{dx}\right)^2 + Hy\frac{d^2y}{dx^2} \right\}$$

$$= m + 2KH + KH\left\{ \left(\frac{dy}{dx}\right)^2 + y\frac{d^2y}{dx^2} \right\}$$

Integrating twice:

$$Hy = (m + 2KH)\frac{x^2}{2} + KH\frac{y^2}{2} + Cx + D,$$

where C and D are arbitrary constants to be determined by the known conditions of the case.

Since $x = o$ when $y = o$, we have $D = o$,

and since shearing force at end of cantilever $= L$, we have $H\frac{dy}{dx} = L$ when $x = o$, and $y = o$, or $C = L$, so that the equation becomes,

$$Hy = (m + 2KH)\frac{x^2}{2} + KH\frac{y^2}{2} + Lx$$

or $x^2(m + 2KH) + y^2 KH + 2Lx - 2Hy = O$

This is an equation to an ellipse, whose major axis is vertical, the ratio of the squares of the axes being $2 + \frac{m}{KH}$. The vertical tangent to the ellipse at the end of its minor axis touches the curve at the point where $y = \frac{1}{K}$, so that the depth of the longest cantilever that can be built with these loads, is $\frac{1}{K}$ at the abutment, and is independent of m, H and L.

It will be noticed that the form of the curve is independent of a, the length of the cantilever, when H has been chosen.

It is possible to determine the value of H, which for any given length of cantilever of this elliptic form, will make the total weight a minimum, and this would be a method of determining the depth at the abutment, but such an investigation would be merely a mathematical exercise, under hypotheses so remote from the facts as we have hitherto assumed, and results in a depth which is obviously too great for practical economy. In the first place diagonal bracing must be supplied to meet the case of moving loads, and as the depth is increased, this bracing becomes heavier. Secondly, all secondary bracing becomes heavier as the depth increases. Thirdly, all compression members in the web will have a smaller allowable stress per square inch as the depth increases, owing to their greater length, and so their weight is increased. Fourthly, the cost of erection will in general be increased by employing an excessive depth. Fifthly, a greater depth would properly be chosen for a cantilever where anchorage had to be provided, than where two adjacent cantilevers counterbalanced each other, owing to the greater depth reducing the material required for guys and anchors. For all these reasons, it will be seen that it is useless to attempt to calculate the proper depth for a cantilever without a very extended investigation, for which the data are not at present available, but both theory and experience point to the advantage of choosing a greater depth than would be chosen for a girder bridge. An ordinary proportion for a large girder bridge would be $\frac{1}{7}$th to $\frac{1}{8}$th of the span, and if for the girder were substituted two cantilevers meeting in the middle of the span, the depth might with advantage be considerably increased beyond this proportion at the abutment, if it be reduced to nothing where the cantilevers meet. When a central span is also introduced, resting on the ends of the two cantilevers, the concentrated load on the end, gives a reason for still further increasing the depth at the abutment *proportionally to the length of the cantilever.* Probably, the greatest depth that could economically be used is nearly reached in the Indus Bridge (Fig. 2), where the depth at the abutment is ·54 of the length of the cantilever. In this case, backstays over 300 feet in length had to be provided with an aggregate estimated stress of 2,400 tons on them at each abutment and anchorage to hold the backstays, so that a very great depth was justifiable. Except where the anchorage causes a considerable proportion of the total weight, a proportion of $\frac{1}{8}$ of the length of the cantilever would probably be ample but each case must be considered on its own merits. It should always be borne in mind in considering such problems as this, that it is of the

nature of a continuously varying quantity, that its value varies very slightly for moderate variations from the conditions which make it an absolute minimum. Thus, if a depth be chosen for a cantilever which is not widely different from that which makes the quantity of material a minimum, the weight will be only slightly increased, while it is possible that great structural advantages in other directions may be gained. In recommending a great depth for a cantilever at its abutment, it is assumed that the depth will be continuously reduced from the abutment outwards. If the load were uniformly distributed, it is by no means certain that a cantilever of uniform depth would require more material than one of varying depth, but we have already pointed out the great extent to which the weight of the structure itself necessarily varies, and if the concentrated load at the end were separately considered, the economical truss for it is a simple triangular frame of very great depth. From the point of view of economy, it would be well to reduce the depth of the cantilever to nothing or to a very small amount at the outer end, but in many cases, it is thought well to maintain a depth at the end of the cantilever, equal to that of the central span at its end, in order that the latter may be built out without false works, under the same system of erection as is pursued with the cantilever. In the case of the Indus Bridge (Fig. 2), the plan to be pursued is to throw a suspension staging over the 200 feet interval between the ends of the cantilevers, on which to build the central span. With the Hooghly Bridge, the 420 feet side spans were built on shore complete with cross girders, etc. One end of a span was built overhanging the abutment, so that a pontoon could be brought under it, and it was then towed out to the cantilever, the other end running on rails on shore.*

A most important point to consider in choosing the depth and form of a cantilever, is the effect of the choice made on the angles of the diagonal bracing and on the length of the panels in the cantilever. If the panels be short and a great depth diminishing rapidly away from the abutment is used, the angles of the diagonal bracing will be unfavorable to economy near the abutment. This difficulty may be avoided by using a double system of triangulation over the deeper part of the cantilever only, or even in a large span a treble system for some distance, and the objections justly urged to multiple systems of triangulation in trusses, lose most of their force in the case of large cantilevers. In the first place, the method of erection by building out, ensures each diagonal taking its proper share of the dead load. In the second place,

* The erection of this bridge is described in a paper recently presented to the Institution of C.E. England, by Sir Bradford Leslie, K.C.I.E., who carried it out.

with respect to the rapid variations of stress in the web members from moving load, to which two or more systems of triangulation give rise, it should be remembered that it is only in large spans that a double system could have anything to recommend it, and then only near the abutment where the stresses are greatest, and that in such cases the moving load only produces a small portion of the entire stress in the web. In case a single system of triangulation, changing to a double system, is used in one part of a cantilever, it is desirable to provide for a fair division of the stresses from dead load between the two sets of bracing in the double system, which might be done in more than one way. A compromise has to be made in practice between different requirements; and the depth must be kept within such limits as will admit of reasonable proportions in other respects, while the diagonal ties or struts may be allowed to vary in inclination to some extent from one panel to another.

The effect must not be neglected which the choice of panel length has upon the weight of the floor system, since it is just as necessary to observe economical proportions in that part of the bridge as in any other and since it is obviously undesirable to attach cross girders to any part of the main trusses except where they are directly supported by the web members, if it can be avoided. The principle to be observed here is as follows (and has not so far as we know been stated before). There is a minimum thickness for the web of a plate girder, beyond which it cannot be reduced however small be the stresses in it. What this minimum should be is a matter of opinion, but having decided on it, the cross girder should (if otherwise practicable) have a web of this thickness, and the spacing of the cross girders should be such as to take full advantage of the strength of the web; that is to say, the spacing should be such as to bring on to each cross girder a load that strains the metal of the web up to its limiting permissible stress in that position. The limit will generally be reached in the bearing area of the rivets through the web, before it is reached in the shearing section of the web itself.

If the spacing of the cross girders be wider than this, the total weight of cross girders will remain unchanged, supposing them to be accurately proportioned to the stresses, because the load on each cross girder increases directly as the space between them, and the number of cross girders diminishes as the inverse of the same ratio. But while the total weight of cross girders remains unchanged, the weight of rail-bearing beams increases rapidly as their span increases, so that the total weight of the floor will be increased, if the interval between cross girders be greater than that fixed by the above principle. But it should

be observed that the proper spacing for cross girders thus arrived at is greater as the length of the cross girder is greater and in direct proportion to it. For the depth of the cross girder will be a constant fraction of its length, and therefore the safe load on a web of a given thickness will be proportional to the length of the cross girder. This is important for the reason that it is not unusual to make cantilevers of a tapering form in plan, i.e., with width diminishing from the abutment outwards, to give greater stiffness against wind. If this be done, the cross girder will vary in length and will be longer where the cantilever is deeper (if the depth vary), and we thus find that where we wish to use longer panels in the main trusses, we shall promote economy in the floor system, by using them. The qualification must be observed, that when the cross girder reaches such a length as to make a framed truss more suitable for it than a plate girder, the principle above set forth ceases to hold good, because the weight of the cross girder (of given length) is then approximately proportional to its load, and therefore the same per foot run of the bridge, whatever the spacing may be. (We are here neglecting the consideration of the effect of the weights on separate axles of a locomotive which would modify these conclusions where the cross girders are very close together).

The panels should in no case be allowed to get too long, not only for the sake of keeping down the weight of the floor system, but also because the difficulty of erection by building out will be vastly increased, and also because it will entail strengthening of the booms to resist the local action of their own weight.

Although it is impossible to lay down general rules, owing to the extent to which the circumstances of different bridges vary, yet it may be said, that when the conditions admit of it, the type of cantilever that will generally prove the cheapest, taking into account facility of manufacture and erection, is the truss with vertical posts, with one horizontal boom and with one boom inclined and straight throughout. The St. Lawrence bridge (Fig. 4.) is a good example of this type. If the tensional boom be horizontal, the diagonal ties are shorter, while if the compressional boom be horizontal, the weight of the two booms together will be somewhat less. A form more pleasing to the eye is obtained by making the lower boom curved. By this means the web stresses, may be largely reduced, but the increased length of the web members and the additional weight in the lower boom, will usually more than neutralize this advantage. The expense of manufacture will be also increased by a curved boom, and therefore it is not to be recommended except from asthetic considerations, which are of course in certain

cases of the highest importance. If a curved boom is used, it should be sufficiently flat to allow of each length of boom from joint to joint being made straight, without marring the outline, and the central span should, if possible, have a curved boom of continuous curvature with that of the cantilever. The best way of effecting this is by employing a hinged braced arch (as proposed by Mr. C. B. Bender*) instead of a truss for the centre span. The hinged arch by means of a temporary connection with the tensional boom of the cantilever, can be built out without false works in exactly the same way as a trussed center span can be. The effect of substituting an arch for a truss in the centre span is to increase largely the stress on the compressional boom of the cantilever, and at the same time to relieve the stress on the tensional boom and the anchorage. Care must be taken that under no circumstances shall the stress on the tensional boom be reversed.

The proportion which the length of the centre span† is to bear to that of the cantilevers, will generally be very largely governed by the proposed manner of erection, but in any case it is a matter of interest to know what proportion would be the most economical, and if that proportion cannot be used, it is desirable to know how the total quantity of material in the bridge will vary with the different proportions that it may be open to us to select. The mathematical analysis of this problem in general is surrounded with great difficulty, unless hypotheses are made which remove it out of the region of practical utility, but for any such type of cantilever as that of the St. Lawrence bridge, the following method will give all the desired information with sufficient accuracy for the purpose. The general features of the design are supposed to have been provisionally settled, and it is only required to determine how the total weight will be affected by varying the length of the cantilever portion of the bridge. The vertical loads only need be considered, because the material needed to resist wind stresses, although very considerable in large bridges, will not seriously affect this particular question. If however great refinement is wished for, the wind pressures may also be taken into account by an extension of the same process. The stresses in the cantilever arise from two sources, (1) the load on its end from the centre span, which varies, of course, with the length of that span; (2) the moving and dead load on the cantilever itself. Let a skeleton diagram be made of a cantilever extending to half the entire span of the bridge in length, or to whatever may be the greatest length it would be possible to make the can-

* "Principles of economy in the design of Metallic Bridges," New York: Wiley and Son, 1885.

† This term is used for brevity to denote any span resting on the end of the cantilever.

tilever. Shorter cantilevers will then be represented by cutting off one two or more panels from the cantilever at the abutment end, and the stresses in all the members would remain unaltered by shortening the length in that way if the loads remained unaltered. Let the stresses in the cantilever now be calculated, (*a*) from a load of 100 tons on the end of the cantilever together with the loads from the approximate weights of the members themselves, only so much metal in the members being considered as is necessary to carry the load of 100 tons at the end; (*b*) from the moving and dead loads on the cantilever, neglecting the load on the end from the centre span, but including the approximate weight of the members of the cantilever, as necessitated by the loads here considered. The weight of the cantilever itself is thus divided into two parts, one of which is dealt with in (*a*) and the other in (*b*): these parts must, of course, be assumed in the first instance and then corrected by the result of the calculations. We thus form a Table of the weights of cantilevers of various lengths differing successively by one panel. The labor in doing this is not excessive, because we do not require results correct *in themselves*, but only results which are comparable with each other and relatively correct, and it is not necessary therefore to have great exactness in the permissible stresses per square inch, in compression members, or in the percentages to be added for covers and secondary bracings and so on. A concentrated moving load is easily dealt with, as its effect on the whole of the boom is greatest when it is at the outer end of the cantilever, and on any member of the web when it is concentrated as nearly as possible above the outer end of that member. Thus the process of getting at the weights of cantilevers of various lengths loaded as in (*a*) and (*b*), is merely one of sucessive summation, one panel after another being added and no calculations repeated, as they would have to be in independent girders of different span. Next, (*c*) let the loads be calculated which are imposed on the end of the cantilever by central spans of different lengths. This load is made up of half the dead weight of the central span and of more than half the moving load (if the moving load is not assumed as uniform). Finally make a list of the probable weights of material in the main trusses of centre spans of various lengths, taking care that the weights correspond to the kind of truss which it is actually intended to use, and that they include only such parts as enter into the estimates previously made of weights of cantilevers. This list can be obtained from weights of existing bridges, by estimating for one span in the same manner as the cantilever was estimated for, and then comparing the result with the usual weight of bridges of the same span and type, which will give a

factor for reducing the usual weights of other spans so as to make them comparable with the cantilever weights. We now have material for filling up a Table such as the following:

1	2	3	4	5	6	7	8
Length of each cantilever.	Length of Central span.	Load on Cantilever from central span resting on it, in hundreds of tons.	Weight of Cantilever for every hundred tons of load on its ends.	Weight of cantilever due to load of central span resting on it.	Weight of cantilever due to its own load.	Weight of ½ Central span.	Weight of one Cantilever and of ½ central span together.
ft.	ft.						
300	0						
290	20						
280	40						
270	60						
260	80						
250	100						
240	120						
230	140						
&c.	&c.						

We have here supposed the table to be formed for a total span of 600 feet, which is to be made up of two cantilevers and a central span resting on them, and we have supposed it to proceed by differences of 20 feet in the centre span. All the rows of figures in such a table as this need not necessarily be calculated. Some may be filled up by interpolation. Columns 4, 6 and 3 are the results of the preliminary calculations [a] [b] and [c] described above. Column 5 is obtained by multiplying the figures in column 3 by those in column 4. Column 8 is the desired total weight, and will show the relative economy of different arrangements. The figures in column 8 will not, of course, agree with those of an actual bridge, but the *differences* between them will, if the calculation is properly made, be the differences between the weights of actual bridges, because in the estimates everything will have been considered which could cause a difference to arise. The Table given above by way of illustration must, of course, be modified to suit the circumstances of different sites. For instance, instead of two equal cantilevers and a central span, a case like the Hooghly Bridge [Fig. 3] may arise, where there is for each opening one cantilever and a shore span, and in which the amount of material between the piers, necessary to resist the bending moments at the piers, must enter into the comparison. Again, where anchorage has to be provided, another column of

weights must be added for the weights of backstays and anchors, and must be summed along with the weights of other parts of the bridge. All this calculation may appear somewhat irksome, but in the case of a large work, extensive calculations can be afforded if their results are trustworthy; and when the alternative is only to act on irrational analogies from other works, or on imperfect formulæ, a considerable amount of such preliminary labor should willingly be undergone.

The weight of anchorage material necessary is proportional to the bending moment at the abutment and inversely as the depth of the cantilever, other things being equal. If the backstays are straight and terminate at a given level, the most economical angle for them is 45°, regarding only the section necessary in them to meet the stress; but by making the angle with the horizontal a little less than 45,° a certain amount of material may be saved in the joints of the backstays and also in the anchors, which more than compensates for the increased weight of the backstays themselves.

Where other spans have to be built adjacent to a large cantilever span, it should not hastily be assumed that the proper plan is necessarily to counterbalance the cantilever by an adjacent cantilever in the opposite direction. Where good foundations exist and piers would not be expensive, it may be cheaper to build a number of short independent side spans, and anchor the cantilever independently of them. If this is done, care must be taken to provide in the abutment for the unbalanced thrust in the lower boom of the cantilever. In estimating for a centre span, resting on two cantilevers, it must not be forgotten that every ton of weight in it has to be paid for again in extra weight in the cantilever, and, therefore, it is justifiable to incur greater expense than otherwise would be advisable, where weight can thereby be saved, as for instance by using the highest class of material both for trusses and floor, and the lightest forms of connections.

The joint between the central span and the cantilever requires careful consideration, the connection should be such as to fulfil the following conditions:

[1] Both cantilevers must be free to expand and contract from change of temperature.

[2] The wind pressure on the central span must be equally borne by the two cantilevers.

[3] There must be longitudinal support for the central span to resist the effect of a braking of a train on it or a wind blowing diagonally.

[4] The connection at both ends must have sufficient lateral rigidity

to check undue lateral vibration. Conditions (1) and (3) would be fulfilled by supporting the central span like any ordinary bridge truss, on a rocker bolted down at one end and on a rocker resting on expansion rollers at the other, but this would not satisfy the second of the conditions. A better plan would be to support the span by rollers or links at both ends, and to secure the centre span to one cantilever only by a large vertical pin on the centre line of the bridge adapted to transfer all the lateral shearing force. A similar pin at the other end, free to move in an elongated hole, would also be the most satisfactory way of transmitting the shearing force at that end also. The points of contrary flexure of the whole bridge under wind pressure would then be fixed, and all uncertainty as to wind stresses removed. The plan adopted in the Indus Bridge is to have expansion rollers at both ends, and to connect the span to both cantilevers by horizontal bolts along the centre line of the bridge, by which an initial compression is put on rubber springs enclosed in cylinders. These bolts do not transmit any shearing force, but only serve to make the expansion equal at both ends, and remove the necessity of bolting down the span to the cantilever at one end. The springs are not stiff enough to put any serious additional strains on the bridge under the greatest changes of temperature. The wind pressure on the central span is transferred to the cantilevers through a sliding contact.

The study of the deflections and deformations of bridges has been too much passed over in works on the subject; and as it is one of great importance in relation to cantilevers, we will devote a little attention to it. It is advisable to ascertain if possible the nature of the deformations which a bridge will undergo under its loads, before building it, and not to depend simply on observations taken when the bridge is tested, because a study of the deformations may give valuable hints as to improvement in design.

Whether the joints are hinged or rigid, it is permissible to treat the structure as a framework with frictionless hinged joints in the first instance, as is universally done in calculating the stresses in the various members. With this assumption, the deformation may be calculated either graphically or analytically. Where the angles between the web members and the booms are not constant, the graphic method is the most rapid, and in any case would be useful to check calculation, and as giving a general idea of the deformations at a glance. It rests on the following propositions:—

(1) †If a diagram be drawn representing a given hinged framework

†This proposition and the analytical expressions below are given, so far as we know, for the first time, though they are likely to have occurred to others. The geometrical proofs of them are comparatively simple.

on a scale of $\frac{1}{m}$, and if starting from a fixed point and a line of fixed direction in the framework, the diagram be re-drawn with its lines increased or diminished in length, by the full size elongation or compression of the various members of the frame-work, then in comparing the two diagrams thus obtained, the change of position of any point in the diagram is the actual movement under strain of the corresponding point in the structure, and the change of angle of any line in the diagram is m times the change of angle of the corresponding line in the structure.

The only proviso is that the scale of the diagram must be sufficiently large that the elongation or compression of any member may still be a small fraction of the line on the diagram affected by it; the fraction may be 1-20th without seriously impairing the accuracy of the results.

[This method applies of course to other structures equally with cantilevers. In the case of independent trusses the deformation would be plotted, commencing from the middle of the bridge, where under a symmetrical load the booms are horizontal.]

If the analytical method be used, let ABYX (Fig. 7) be one panel of a cantilever whose booms AB and XY make respectively angles $\alpha°$ and $\delta°$ with the horizontal. Let l_1, l_2, l_3 be the distances respectively of X, B and Y from the vertical through the extremity of the cantilever.

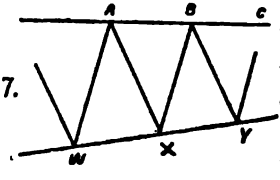


Fig. 7.

Then if the length AB of the top boom be expanded by an amount $K_1 \times AB$ the vertical deflection at the end of the cantilever due to this change, all the other members of the cantilever remaining unaltered in length, is :—

$$(2) \qquad \delta_1 = \frac{K_1 \cdot AB \cdot l_1}{BX \cdot \sin ABX}$$

Similarly for the length XY of bottom boom contracted by an amount $K_2 \cdot XY$:

$$(3) \qquad \delta_2 = \frac{K_2 \cdot XY \cdot l_2}{BX \cdot \sin BXY}$$

For the diagonal tie BY:

$$(4) \qquad \delta_3 = \frac{K}{3} \left\{ \frac{BY \cos \beta}{\sin BYX} - l_3 \, (\cot YBC - \cot BYX) \right\}$$

For the diagonal strut BX:

$$(5) \qquad \delta_4 = \frac{K}{4} \left\{ \frac{BX \cos \alpha}{\sin ABX} - l_2 (\cot BXY - \cot ABX) \right\}$$

These expressions are here given in their most general form. In any

particular case they will be much simplified. For instance, when the booms are parallel, (4) and (5) consist of their first term only. If in addition the strut BX is vertical, sin ABX in δ_1 and δ_4 is unity. K varies according to the stress per sq. inch, but usually k_1 will be nearly equal to k_3 and k_1, k_2 and k_3 will not vary much from one panel to another. In tension members, of course, the gross section must be estimated in order to determine the elongation, where in calculating stresses deductions would have to be made for rivet holes.

Some useful deductions may be made from the propositions given above.

Consider two similar cantilevers whose linear dimensions in all directions are as $m_1 : m_2$, and whose external loads are in the same ratio. The stress per sq. inch. on corresponding members of the two cantilevers being the same, we see at once that the deflections will be in the ratio of $m_1 : m_2$. The angular deformation will be the same in both cases. Let us now compare the secondary stresses to which these angular deformations give rise, if the two cantilevers compared be rigid at the joints and not hinged. The form of the booms under strain will be a curve of continuous curvature, passing approximately through the positions of the joints given by the diagram of deformation in which the joints were treated as hinged. It will not be accurately so, because at each joint the web members and the boom act on each other with equal and opposite couples, and also the curvature of any web member, by shortening the distance between its ends, tends to elevate the lower boom and depress the upper; but the effect of these forces will not modify the form of the boom to any great extent compared to the whole deformation.

It follows then from the similarity of the figures that in the two cantilevers compared, the radii of curvature of the booms at corresponding points are as $m_1 : m_2$. Let ρ be the radius of curvature, r the distance from the neutral axis of the boom to its most strained edge, t the stress per sq. inch, at that edge due to flexure, and let the subscript figures 1 and 2 in all cases refer respectively to the two cantilevers under comparison.

$$\text{Then } t = \frac{E.r}{\rho}$$

$$(6)\ \text{Therefore } \frac{t_2}{t_1} = \frac{r_2}{r_1} \times \frac{\rho_1}{\rho_2} = \frac{r_2}{r_1} \times \frac{m_1}{m_2}$$

Now confining ourselves to the compression boom in which r (and therefore t) is of course much greater than in the tensional boom, r will in general be made a certain proportion of the panel length, since the

boom has to be treated as a column with fixed ends, from which we see that if the panel length increase in proportion to the size of the bridge $\frac{r_2}{r_1} = \frac{m_2}{m_1}$, and (6) becomes $t_2 = t_1$, *i.e.*, the stress due to flexure is constant. In any case if the depth of all individual members of the webs or boom is proportional to the span, the stress per sq. in. due to deformation is the same in corresponding members in all spans. This is an important fact, because, with very large bridges, pin connections become difficult, owing to the large size of pins and eyes required, and therefore it is important to know that the objections to rigid connections, founded on the secondary strains they give rise to, do not become greater as the span increases.

In order to ascertain the changes of figure due to deformation (on which depend the secondary stresses in the structure), the changes of angle must be investigated.

Let Δ_1 be the increase in the angle AXW due to deformation, supposing the joints to be frictionless hinges, Δ_2 the increase in AXB and Δ_3 that in BXY.

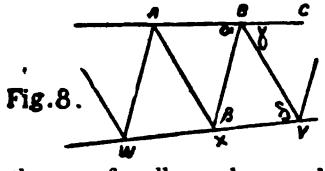


Fig. 8.

Assume for simplicity, that K is the same for all members, and that AW is parallel to BX, and AX to BY.

Then $\Delta_1 = 2\,K\,\{\cot(\beta+\delta).\}$

$\Delta_2 = 2\,K\cot\alpha.$

$\Delta_3 = 2\,K\,\{\cot\delta - \cot(\beta+\delta)\}$

If Δ be the angle between WX and XY after deformation

$\Delta = \Delta_1 + \Delta_2 + \Delta_3 = 2\,K\,(\cot\alpha + \cot\delta)$.

Suppose now Θ to be the angle between the booms (assumed to be straight). Then $\alpha = \beta + \Theta$ and $\Delta = 2\,k\,\{\cot(\beta+\Theta) + \cot\delta.\}$

If then β and δ be given, Δ is a maximum when the booms are parallel and diminishes continually as Θ increases, thus showing that the distortion of the booms is less for a cantilever of varying depth than for one of uniform depth.

For a given value of Θ, if β and δ vary, it will be found that Δ is a maximum when B is the point of contact of a circle through XY touching the line A B. Δ vanishes when $\alpha = \pi - \delta$.

The web members, however, have each a bending moment at the end, and there must be a couple acting on the boom, equal and opposite to the sum (or difference) of the couples acting on the ends of the two web members meeting at the point of the boom in question. Thus, when the form of a frame with frictionless hinges under strain would be the

figure as shown in dotted lines (the booms being straight because $\cot \alpha + \cot \delta = o$) —then if the joints be rigid, the booms and webs would be distorted as shewn exaggerated in full lines, all angles at every joint being the same as those in the original figure. If, however (as is generally the case in pin bridges), the booms (or one of them) be continuous, and the web members be hinged, then neglecting friction of pins, in such a case, when $\cot \alpha + \cot \delta = o$, the boom which would suffer distortion if $\cot \alpha + \cot \delta$ were not zero, will remain straight under strain. This happens in the annexed figure when ang. WAB = ang. AXW.

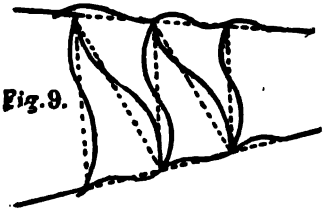


Fig. 9.

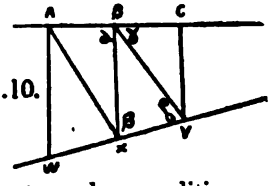


Fig. 10.

In practice, only an approximation to such a condition could be realized, because the panel could not be allowed to vary so rapidly in length as constant angles for bracing would necessitate.

But if for ties AX and BY, struts BW and CX were substituted, it will be seen that $\cot \alpha + \cot \delta$ becomes much larger at once, and the strains on the compression boom, which is necessarily continuous, will be much greater.

If B lie outside the two positions on AC given by $\alpha = \pi - \delta$, the curvature of the lower boom will be upwards because Δ becomes negative. Take the case of a girder of uniform depth; $\alpha = \beta$ and $\gamma = \delta$

Let d = depth

a = length of panel

$a = d (\cot \beta + \cot \delta)$

$$\therefore \Delta = \frac{2Ka}{d} \text{ or } \frac{\Delta}{a} = \frac{2K}{d}$$

Therefore the deviation of the boom per foot of length is constant and independent of the angles of the bracings. It is proportional to the stress per sq. inch and inversely proportional to the depth.

Attention should be directed to the deformation of the lower boom of a cantilever or continuous girder at the abutment. If a diagram be drawn, as recommended above, to ascertain the general deformations of the structure, it will be found that the angular deformation of the lower boom is greater at the abutment than at other joints, and is sometimes such as to give rise to very serious secondary strains in the boom,

when the joint at the abutment is rigid. The cause of this is the sudden reversal or vanishing of the shearing force in crossing the abutment.

The same effect would occur in ordinary truss girders at the *middle*, but in this case it is always mitigated by the fact, that the web members in the middle of the truss are necessarily almost unstrained from primary stresses where reversal of shearing stress takes place, being designed for maximum shearing at that section from unequal loading; and also because the section cannot be reduced to almost nothing, as the stress is, and so the great stiffness (comparatively) of the web relieves the boom of local distortion. The difference is that in cantilevers the shearing stress rises to a maximum at the abutment and then suddenly diminishes. In trusses it diminishes to zero at the centre and then increases in the opposite sense.

To those whose ideas of flexure in girders are founded entirely on the theory of flexure in beams this would not readily occur, for that theory makes the curvature depend solely on the bending moment according to the equation $\rho = \frac{E.I}{M}$ This follows from the assumption that all particles of the beam lying in one plane normal to the neutral axis before strain will lie in one normal plane during strain, an assumption which is plausible enough for beams, but can have no relation whatever to the flexure of a hinged framework.

We have seen however in equations (4) and (5) how the deflections are affected by the shearing stresses, and in that view it need not be surprising that a sudden and great change in the shearing stress causes great local deformation. The remarks apply equally, of course, to continuous girders as to cantilevers, and point to the desirability of hinging the lower boom at the abutment when practicable.

The calculation of deflection in a cantilever may sometimes be facilitated in the following manner. Suppose, by way of illustration, that the stresses on all the members of the bridge in tension are not far from 5 tons per square inch of gross section and that the compressional stresses range from a to b tons. The form of the bridge would be unaltered by an equal compressionable stress per square inch applied to all members alike, for this would simply make the bridge shrink in all directions alike, a similar result to that produced by a fall of temperature. Imagine then an initial compression of five tons per square inch applied to all members. This produces no angular deformation, but only a shrinkage equivalent to slightly altering the scale of the drawing. Now combine this uniform stress with the actual stresses in the bridge and we have the tensional stresses so nearly neutralized, that they

may be neglected, and the compression stresses varying from a + 5 to b + 5 tons per square inch. By this means we are saved the labour of calculating the effect of change of length in half the members of the bridge. If this modification is applied to the graphic method, the resulting diagram will, in its angles, be unaffected by the modification. To have the linear deformations correct, the whole diagram of deformation must be supposed expanded by the amount of the initial strain. If for instance the abutment be d ft below the end of the cantilever the deflection given by diagram or calculation will be in excess to the amount of K d t where K is the compression in a foot of length due to a stress of 1 ton per square inch, and t tons per square inch is the initial compression supposed to have been applied.

From the drawings accompanying this paper, Plates III, IV, V and VI have been prepared.

DISCUSSION.

Mr. C. Bender. Responding to the kind invitation of the Canadian Society of Civil Engineers, the writer ventures to make some remarks regarding Mr. Findlay's paper on Cantilever Bridges.

The author agrees with the writer on many points, but on several others the views are much at variance.

In the first instance, the writer holds it to be of great importance that a clear idea should be had as to what a cantilever bridge really is, for this reason: that a continuous bridge with hinges, and that other designs of the solitary beam, fixed with the minimum expense at its ends, and provided with an independent middle span of suitable length, are entirely different structures, and have to be designed for essentially different conditions. He at once excludes such bridges, which for the sake of one fixed span are provided with one or even two heavy outside spans over dry land. Such structures have no reason of existence, and are the more objectionable, as the entirely erroneous idea has crept in that it is economical to make long cantilevers, and consequently very great moments of flexure at the piers. If continous bridges must be built, there must be good reasons for making several spans, there must be deep water to be crossed.

Perhaps it will not be out of place to trace the scientific development of this class of bridges in general, which form the subject of Mr. Findlay's paper.

At the end of last century the French savant, Pierre Simon Girard, translated the theory of flexure, which the immortal Leonard Euler had given in 1744, and extended this theory, which to-day goes by the name of Navier, to the beam fixed at the ends. About 10 years later Poyet, in France, proposed what the writer termed stay-bridges, consisting of two pairs of masts, anchored back, and carrying the floor by inclined tension rods or stays, and compression-members abutting against each other at the feet of the masts. His idea was taken up in Germany, and in 1825 the first modern cantilever bridge was built over the Saale at Nienburg. The designer had already a tolerably clear understanding as to economy. The span was 240 feet in the clear; the wooden towers were 40 feet high, the anchorage bars were manifold, but inclined in the average at an angle of nearly 30 degrees. A short drawspan in the middle was added to accommodate the passage of

ships. The bottom chords were of wood, abutting against masonry; the stays were of iron. This bridge, however, had but a short life. It only cost 8,000 dollars, inclusive of abutment and anchorage arches, and though it stood its tests, for some unknown reason, though unloaded, it fell several months later. As a peculiarity of this structure, it may be mentioned that the suspension stays were kept in straight lines by a system of light distance pieces or struts, which in concentric lines intersected the stays and back-stays at nearly 90 degrees, in the same manner as was proposed for a similar design by Messrs. Flad and Pfeiffer in 1875, for the projected Blackwell's Island bridge in New York.

In 1865 C. de Bergue in England patented continuous girders with hinges, but properly speaking this patent was an extension of designs proposed by Joseph Langer in Austria. At that time so little attention was given to this novelty, that in 1866 it could be reinvented by the practical bridge engineer Gerber in Germany, and a year later by the writer in the United States.

In the year 1873 the writer had occasion to make estimates for an intended bridge over the Niagara river, and the idea struck him to utilise the cantilever principle of erection already proposed by Pope of New York, then by Telford in 1811, and executed by the Engineers of the St. Louis arch-bridge, by making the material necessary for such an erection a permanent and necessary part of the bridge. The arch should be very deep, hence broad at the base, and not wider at the top than necessary for the floor. The outcome was the writer's arch bridge with five hinges.

The design, however, is not simply a three-hinged arch set upon the ends of two cantilevers, but it is entirely different in principle from the cantilever bridge. It is a bridge with but one pair of chords, a real arch, but with five hinges. If the whole arch is uniformly loaded this bridge will act as a theoretically perfect arch. The two hinges between the crown and the abutments are so placed that they must be fixed in position, in such a way that in certain cases of loading the bridge they cannot move upwards or downwards. The unloaded bridge again is an arch, and has hardly any strains in the anchorages.

In order to prevent reversal of strains in the anchorages, so as to permit the use of tensile members instead of tie-struts, also to make the middle arch deeper, hence more economical for very large spans, the writer afterwards added the arrangements which Mr. Findlay mentions, consisting of the provision by which the protractions of the end-

tangents of the middle arch pass sufficiently underneath the abutments of the whole arch.

For moderate spans, the arch is more in place where the question is to erect a deck-bridge. If a through bridge were intended, a difficulty would arise how to carry the wind strains from the arch above down to the floor below, and yet how to leave a way for the passage of trains. Arches being in an unstable equilibrium must be thoroughly braced together. This problem indeed arises with all through bridges, only that they have tensile chords on which stiff frames can be erected, holding the joint points of the top chords in position. However, not many through girder-bridges are at all properly braced transversely at their entrances. Such bridges, especially pin jointed structures, which not only have a smaller number of stiff members in their webs than rivetted lattice girders with stiff members throughout, and therefore should be fitted with especially stiff and carefully calculated ends, are frequently found, and are still constructed with loose suspenders instead of posts, entirely out of place where the tensile chords consist of eye bars. These loose hangers are nowhere more out of place than at the first panel points from the end-bearings of a bridge, and with the parsimoniously designed portals are among the causes why it is so easy to push such bridges from their piers.

All such bridges should be well provided with carefully designed end-posts, which should be stiffly connected at their feet as well as above the open space for the passage of carriages.

Thus it is seen, and it is illustrated by the many accidents occurring to scantily braced through bridges, that it is not very easy in case of a small or a moderate span of through arch, to comply with these conditions of transverse stiffness against wind. In reality it would be necessary to build for every panel a thoroughly stiff frame which would hold the arch points above the floor in position, and would have to receive its basis from a couple of continuous chords in the plane of the floor, thoroughly braced to receive the whole windstrains. On this basis stiff frames or diaphragms would have to be erected to hold the joints of the arch in position.

But all these preparations combined with the abutment masonry would destroy the economy of the arch, so that only the erection on the cantilever principle would remain, and perhaps the graceful appearance of the design.

In the case of very great arches, however, the question of safe and scientific bracing is not offering any great difficulty, and for deck-arches there is none whatever.

The through cantilever bridge of Girardot, of 328 ft. span, designed in 1879, and the arch-bridge at Honda with five hinges designed in 1883, comply with the conditions of transverse stiffness against wind, and the manner in which these conditions are fulfilled is illustrated in the writer's book, kindly mentioned by Mr. Findlay. These two examples at the same time show how the writer thought a better appearance might be given to such structures, and, having discussed the conditions which limit the use of the arch bridge with five hinges, he returns to its merits as regards economy.

If engineers have an opportunity of utilizing the advantage offered by locality towards dispensing with tensile chords, by abutting curved top chords against firm rock or economical artificial abutments, or if a railway or a city bridge exceeds 250 feet in span, a considerable weight is not only entirely saved, but it no longer loads the bridge which at the same time receives a more graceful appearence.

For all these reasons the arch is very well adapted for spans of extraordinary lengths, and the only improvement necessary is to secure its easy erection.

By anchoring the two end-parts of the arch with five hinges backwards, just enough material is obtained to dispense with false works, and at the same time the moments of flexure of the arch under a one-sided load are reduced to about one-half of what they would be in case of an arch with three hinges, so that again material, which otherwise would load the bridge, is removed from it, and it is utilized to make the anchorage which is thus obtained at no cost at all.

Up to spans of about 550 feet, single span bridges require the least quantity of material. For very large bridges, and where the locality permits it, for moderate spans also, arches are more economical. On account of the high strength (nearly 300,000 lbs. per square inch) and great lengths (in coils of one piece up to a hundred weight) of steel wire, now so cheap, and on account of the very great facility of erection, suspension bridges with suspended well braced stiffening girders, which we now know how to calculate and to proportion properly, compete with great arches.

Continuous girders with hinges, where in place, offer all the advantages claimed for the theoretical continuous girders without their disadvantages.

Cantilever bridges will remain only for localities where erection is difficult and where the arch with five hinges can not be applied. Extraordinary economy can hardly be claimed for them.

According to careful estimates of spans of 1,700 feet, the arch with five hinges was found to be about one half as heavy as the cantilever bridge.

A cantilever bridge, defined by the writer as the single span fixed at the ends, must be designed so that the span itself, plus its anchorages, contains a minimum of material. The quantity of material on the whole forms the basis for comparison, for admitted that eyebars cost more per ton than bars of equivalent strength obtained by adding pairs of joint plates rivetted to them, there remains the difference of dead load important for great spans.

With a continuous bridge, however, the question of anchorage is only of secondary importance, because the outside spans by their own unavoidable weights counterbalance the moments at the main-piers.

What Mr. Findlay says about the proportions of cantilevers refers to this class of bridges, not to the real cantilever bridge or the single span fixed at the ends.

He also says that the theories hitherto given towards proportioning cantilver bridges are all vitiated by not considering the non-uniformity of the permanent loads of cantilevers.

This objection, which, if true, would overthrow the writer's own, investigations as published in his book, however only holds good, if the cantilevers were to be designed long and the central span short. This design is only admissible for certain continuous girders, not for the single span fixed at the ends. Of such a bridge the moments at the roots of the cantilevers must be kept moderate in order to make the anchorages economical. In fact, these end moments must be not greater than necessary to erect the *whole* bridge safely without false works. And thus it is at once seen how the distinction between continuous girders and beams fixed at their end leads to the proper design of either class of structures.

It seems to the writer that Mr. Findlay has perhaps underrated the importance of moderate moments at the piers, and overrated the importance of unequal dead loads. If the permanent load of a cantilever at the root is 6 tons and at the end 1 ton, and if the movable load corresponding with it is two tons per lineal foot, the theoretical quantity of this cantilever is only 20 per cent. in the average, less than if the weights were all uniformely distributed.

That with cantilevers of the modern fixed girder, the permanent loads at the piers are still greater than at their ends is an advantage which is not overlooked, but the cantilevers becoming short is of no such importance as to alter the leading principles.

Undoubtedly, if the question were only this: how to reduce to a minimum the material between the piers, the division of the span into cantilevers and middle span would have to be made, so that for very great distances to be bridged, the middle span would carry about one quarter of the whole span, and in this instance the cantilevers would be light at their ends and heavy at the piers.

But if the division were made in a fashion that the middle span becomes $\frac{3}{8}$th to $\frac{1}{2}$ of the whole span, the permanent load at the end of the cantilever would become heavy, and the cantilevers so short, and naturally so deep, as to permit without any appreciable error the supposition of uniform load.

Long cantilevers lead to very great depths, the other design leads to a moderate and more uniform depth, hence to a more moderate width between the girders, and to lighter floors and to the desirable shorter panels.

Besides, if the span were divided nearly in the same proportion as demanded by the ordinary theory of continuity, the girders would also be properly separated to withstand with a minimum of material, and hence expense, the wind pressure. The material necessary on this account in the chords would be reduced to a minimum.

Of the various bridges of that class, such as Mr. Findlay comprises under the common name of cantilever bridges, the writer does not know of one where the problem was more than the design of one or two distinct beams fixed at their ends.

Gerber in Germany, in the year 1867, took the lead with the execution of continuous bridges with hinges. The Kentucky river bridge of the late Mr. Shaler Smith is a continuous bridge scientifically divided, and with scientific parallel chords.

The Niagara bridge of Mr. C. Schneider could have been treated as a real cantilever bridge, the heavy outside staging and counterpassing spans could have been suppressed.

In fact the instances will be rare when long cantilevers need be resorted to at all, and in all instances where the one span has to be chosen, a middle span of about $\frac{3}{8}$th of the whole span leads to an absolute minimum of cost including anchorages. This design leads to bridges of moderate depth and width, with comparatively light webs, and with scientific, clearly understood, and economical provision for the strains arising from wind.

The middle span to be erected on the cantilever principle should have a depth of $\frac{1}{8}$th.

The curves of moments of cantilevers rise rapidly towards the piers, the more reason to adhere to moderate depths, as these great moments

only stretch over a small length, and as in addition the shearing forces are very great at the piers, so that long posts should be avoided if possible.

The variation of depth in the writer's opinion is not a source of any economy in cantilever bridges.

As regards the design of the posts, he takes this opportunity of mentioning that secondary bracing or latticing of such members can and should be avoided. Posts with solid webs are preferable. The author of the paper states correctly that vertical compression members are practically the most economical. Each corresponding couple of such posts should form a stiff diaphragm for the bridge, containing the floor beam and the transverse windbracing. The floor beams cause moments of flexure of the posts, and these moments of flexure should be mentioned in every bridge specification. The posts should be designed as if they were hinged at their ends, and the necessary material should be added to make good the moments of flexure to which they are necessarily subjected.

The Dutch engineers used to build their posts very wide, so as to fit into their broad trough-shaped chords. These posts were made with secondary bracing, lacing or latticing, and the result was that the inne-web diagonals were found to receive other strains than the outside diar gonals. The differences were very great up to 80 per cent., and the strains were even reversed towards the middle of a span.

The Dutch engineers now place castings on the bottom chords which support the cross beams, so that the loads are better distributed.

If the posts were designed with plate webs they would naturally be built less wide, and if in addition the tensile diagonals were placed in the middle of very strong pins, their strains would be practically equal on both sides.

As regards anchorages, a great depth at a pier reduces indeed the counterweight of stones at the end of the anchorage, but it is an error to suppose that it would in the least reduce the minimum material really needed to effect this anchorage. It seems that this error has contributed to the adoption of very deep cantilevers. The quantity of metal for anchorage, once its style is chosen, depends *only* on the moment of forces at the piers. It actually becomes less, not greater, if the height be reduced to its practical minimum.

The anchorage ties, going down from the top of the piers, press on these piers, and the material to resist this pressure becomes less if the piers are reduced in height. The ties have to be kept in straight

lines and must be braced against wind, and the material used in such bracing becomes less if the piers are lower.

The problems of the most favorable designs of anchorages constitute a highly interesting part of the study of cantilever bridges, which are treated in the writer's book. If the retaining ties are anchored to blocks of masonry or to rock, in a manner usual for suspension bridges, their most economical angle of inclination is less than thirty degrees.

The writer agrees fully with the author as to the importance of secondary strains. But who has ever undertaken to calculate them for a bridge with cantilevers of varying depths? He also agrees fully with Mr. Findlay in advocating many fold systems. Panels should be of moderate lengths, if possible no larger than bars can be rolled. The patch-work connected with broad short plates should never be adopted. The design should be for open sections, not round ones, and should be of such a nature that any respectable existing shop could execute it without resorting to new inventions, and the endeavour should be towards good proportions, scientifically correct lateral transverse bracing and towards safe floors.

Finally, the writer would respectfully state that he believes that the desire of building the immense spans, which now are in fashion, is apt to lead to extravagance in design of structures, which perhaps can never earn the interest on their cost. If such should be the result, capitalists would in future hesitate to believe in the estimates of engineers, and the profession in general would suffer for it.

Nothing, in his opinion, would be more likely to prevent such a decline of reputation than the extension of the principle of free trade to a fair competition of talent in the design of bridges.

Prof. Burr

Mr. Findlay has certainly made a very searching statement of the Cantilever Bridge question, and leaves little for the discussion. There are however one or two points on which his remarks may be properly extended.

In the first place, it would be interesting to learn about what relative proportion Mr. Findlay would advise for economy between the length of anchor and cantilever arms, in such types as the Niagara structure where there is no central span continuous with overhanging arms. Approximately five to three (the former representing the anchor arm) gives excellent results with depth over main pier equal to nearly a half of the length of cantilever arm. This leads to some reversion of stress, but not to a sufficient extent to prove in any way objectionable. In fact, in proper design, no valid objection can be effectively

made against such amount of reversion, for instance, as exists in ordinary swing bridges.

The writer can see no proper reason for introducing two or more systems of triangulation in any structure at the present time. That there is some objection, more or less, Mr. Findlay admits; indeed no engineer can deny it. Such a feature is probably as little injurious under the circumstances indicated as is possible, but it is impossible to determine to what extent pernicious uncertainty exists. The facilities for fabricating and handling large bridge members which the best equipped bridge shops now possess enable engineers to avoid such defects of design, and they should do so. Equalizing arrangements are never more than imperfect in their actions, and would not reach the whole difficulty if they were.

The transverse distance apart of the centres of the trusses in a cantilever system carrying a suspended span between the ends of cantilever arms, is not touched by Mr. Findlay, but the following approximate solution of the question is sufficiently near for ordinary purposes.

Let it be assumed that the trusses of a cantilever span should have centres the same distance apart as those of a simple non continuous span, having the same lateral deflection under the same lateral load "w" per lineal foot. Let l_1 be the length of such a non-continuous span and l the length of the cantilever span. Let $0.3\ l$ be the length of each cantilever arm and $0.4\ l$ the length of the suspended span. Then if E is the co-efficient of elasticity and I a constant moment of inertia, the ordinary formulæ for deflection give the relation :—

$$\frac{W}{EI}\left(\frac{0.2\ l\ (0.3\ l)^3}{3} + \frac{(0.3\ l)^4}{8} + \frac{5\ (0.4\ l)^4}{384}\right) = \frac{W}{EI}\ \frac{5\ l_1^4}{384};$$

$$\therefore \qquad l_1 = 0.701\ l \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

If r is the ratio of length over width between trusses for simple non-continuous spans, then

$$D = \frac{0.701\ l}{r} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

is the transverse distance between centres of trusses for cantilevers of the type assumed. If r is 18, Eq. (2) gives $D = \frac{7}{180}\ l$ which is about right. For several apparent reasons the precediag analysis is not by any means accurate, but it yields a very good rule.

Mr. Whited. There are a few points connected with this paper to which the speaker would call attention. One is the author's remark as to the inadvisability of using curved chords.

A curved lower chord, that is, one which changes its direction slightly at each panel point but which is straight between panel points, reduces largely the vertical shearing stresses in the web members; and if the segments are not too long in proportion to their diameter—which very rarely happens—they afford some economy of material, particularly if the web members are very long, and if the chords are rectangular the increased cost of manufacture in a well equipped bridge shop is very slight. In the case of the upper chord, in which the rectangular form is as economical in all respects as any, and cheaper to manufacture, this is still more true, even when the two trusses are not parallel; and if eye-bars are used the cost of manufacture is the same. If rectangular chords and rolled edge plates for splices are employed it is not generally necessary to heat the splice plates to bend them.

The author's investigations on the subject of deflections are very carefully made, and they seem to afford a strong argument in favor of employing pin connections whenever practicable, particularly in cantilever bridges. In his diagram he shows a reversed curvature in all members, but this will not generally be the case in practice because the web members are so much lighter and longer than the chords, so that the reversed curving will all or nearly all take place in them, while the curving of the chords will be continuous, owing to the change of direction at the panel points. The deflection of the web members, of course, never approaches the danger point, but it throws some very considerable stresses upon the rivets connecting them to the chords. It must be observed, however, that the deflection of a long column due to a lateral force still acting is more dangerous than an equal amount of deflection originally existing in this column due to imperfect workmanship.

This matter of lateral stress in long columns is too much overlooked by many engineers in designing bridges and other structures. The speaker knows of a pin-connected bridge, in which the main lateral system is placed more than three feet from the centre line of the chord, and no apparent attempt has been made to stiffen any of the posts. Moreover, the intersections of the axes of the cross struts—which in this case are the floor beams—with the line of the lateral braces are at one side of the posts. To be sure, the floorbeams are rivetted firmly to the posts, but the outside line of safety stringers is more than three feet from the posts. In the particular case in question this may not be dangerous, but the speaker would suggest that in cases in which it is impracticable to place the lateral system nearer the centre line of the chord, the outside line of safety stringers should be placed as near the side of

the bridge as practicable and made to serve the purpose of longitudinal struts, the lateral bracing intersecting on them.

Another point in connection with this matter of deflection, which, although perhaps somewhat foreign to the paper under discussion, is suggested by a glance at the view of the Sukkur Bridge shown in "Engineering" of Jan. 4, 1889. This view may not be accurate in every detail, but probably it is, as it is evidently taken from a photograph. The point is this: Iron and steel are not rigid metals, and when we calculate the stresses in any built structure we must bear in mind the effects which the yielding of any piece due to the stress upon it may have on other parts of the structure. When a bar is subjected to a transverse or an oblique stress, it yields very much more under a given maximum fibre strain, than when it is subjected to a direct tensile or compressive stress. If a curved bar $a\,d\,b$ and a straight one $a\,c\,b$ rivetted together at a and b are strained, either in tension or compression in the direction $a\,b$, the stress in $a\,d\,b$ will be only that due to the elongation of $a\,c\,b$ which produces a bending strain only in $a\,d\,b$. To simplify the investigation, suppose $a\,d\,b$ to be straight from a to d and from d to b, and suppose them to be rigidly connected by the bar $c\,d$. Also, let the bars $a\,c\,b$ and $a\,d\,b$ to be alike in section. Let the stress, (either tensile or compressive) be P and let that part borne by $c\,a = P'$, and that part borne by $d\,a = P''$. Also let $< c\,a\,d = \theta$, $ac = l$, then $a\,d = \dfrac{l}{\cos\theta}$. Now the elongation of $a\,c = \dfrac{P'\,l}{E\,S}$ in which $E =$ modulus of elasticity and $S =$ the sectional area of the bar. The force acting at a to bend $a\,d = P''\sin\theta$, which tends to produce a deflection in the direction $a\,r$ perpendicular to ad equal to $\dfrac{P'\,l^3\sin^3\theta}{3\,E\,I\cos^3\theta}$ and the elongation in the direction $ca = \dfrac{P''\,l^3\sin^2\theta}{3\,E\,I\cos^3\theta}$ in which I is the moment of inertia of the bars, but since $a\,c$ is as stiff as ad, it requires approximately the same amount of force to bend $a\,c$ as to bend $a\,d$: we may therefore assume that the actual deflection $= \dfrac{P''\,l^3\sin^2\theta}{6\,E\,I\cos^3\theta}$ the deflection due to these two forces must be equal therefore,

$$\frac{P''\,l^3\sin^2}{6\,E\,I\cos^3\theta} = \frac{P'\,l}{E\,S}$$

whence $\dfrac{P''}{P'} = \dfrac{6\,I\cos^2\theta}{l^2\,S\sin^2\theta}$

Thus we see that P'' is always very small compared with P'. This difference is increased, when the stress is tensile, by $a\,c\,b$ being deflected in the direction $d\,c$, and thus shortened. When the stress is compressive $a\,c\,b$ is bent toward d, thus diminishing its power to resist compression. The speaker calls attention to these facts because the latticing on the web members of the Sukkur Bridge is made in that manner, so far as he can judge by the above mentioned engraving. It would obviously have been a much better distribution of metal to curve both bars in opposite directions.

When the panel length of a cantilever bridge is great, it would seem advisable to place lateral bracing on the stringers. The speaker has in mind a 20 feet girder span, with $3'' \times 3'' \times \frac{3}{8}''$ angle bars for lateral bracing on both top and bottom flanges, and also a truss bridge having 24 feet panels on the same railroad with no lateral bracing at all on the stringers, and these stringers are not so stiff sideways as the girders in the first mentioned span.

The speaker has read with much interest Mr. Findlay's paper, dealing as it does with a subject on which we have so little literature. There are, however, certain points on which the speaker desires to make a few remarks. Mr. Duggan.

The author in his paper explains a principle to be observed in deciding on the length of panel, which seems to have very little practical value. All ordinary specifications contain some provision for concentrated wheel loads, which can hardly, as the paper states, be neglected. Consider an engine having drivers 7 ft. centre to centre, then evidently, so far as live load is concerned, cross girders placed 2 ft. c. to c., would have to be as heavy as those placed 7 ft. c. to c. The same is true, though in a modified degree, of the cross girders for ordinary panel lengths, on account of the much greater load per foot of the driver base over other portions of the load.

Moreover, the cross girder as a rule is not limited to depth. It would, therefore, be a tedious process to work backwards from a given thickness of web, with a varying intensity of load and a depth variable within fairly wide limits, to find a panel length that would satisfy the limiting values of shear or rivet bearing at the end of the cross girder, but in all probability it would not suit the general outline of the structure.

In all high class specifications, the minimum thickness of web allowed is $\frac{3}{8}$ inch. Taking an economical and practical depth for cross-girder, for double track and width of about 30 ft. c. to c., of trusses, the principle stated would give a very short panel length for any considerable span,

as for 24 ft. panels the end webs would require to be about ½ inch. For single track it would be more applicable, as the width generally requires to be greater than that called for by clearance.

The author says, "A curved boom is not to be recommended except from æsthetic consideration."

For through spans many consider that there is an advantage in using a curved top chord, and the speaker has found in comparative estimates, on a few moderate spans between 400 and 600 ft., an economy of material in so doing.

With eye bar tension members, curving the top chord does not add to the cost of shop manufacture, although it has this objection, that in erection it is difficult to use a top chord traveller and, when this is not possible, necessitates the use of a tall and heavy traveller for erecting the panels near the pier which would be unnecessarily large as the work progressed.

The paper supplies an easy method of comparing the economy of different lengths of centre span; but as the table has not been carried out to the case of a centre span, there are some practical considerations deserving of mention.

If there is no centre span it would be very difficult to form a satisfactory connection at the junction of the two cantilever arms which would provide for shear under live load, and at the same time allow free expansion and contraction.

Again, although a short centre span might be economical of material, economy is not the only object to be sought.

We know that under certain conditions of loading, a cantilever span must necessarily deflect much more than an ordinary truss of the same dimensions.

Under the test loads, the centre span. of the St. John cantilever—477 ft. span—deflected 4 inches; the Niagara cantilever, 470 ft. span, deflected about 6½ inches, after making allowance for compression of steel piers.

These deflections are excessive, and under loads at high speed might produce serious and unknown strains.

According to Mr. T. C. Clarke's table of long span bridges:

The 515′ span of the Cincinnati Southern Railway Bridge, across the Ohio, under test load deflected..... 2″

The 492′ span of the Kuilenberg Bridge..... 1.32″

The 396 span of the Ohio River Bridge at Louisville..... 1⅛″

From the considerations, which also apply to the horizontal wind-

bracing in bridges of moderate span, where the live load bears a large proportion to the total load, it would seem advisable to make the centre span as long as can be conveniently erected, and the conditions will allow.

In speaking of the joint between the centre span and the cantilever, the author mentions four considerations to be observed, which have been easily met in America by hanging the centre span on a long link and making a sleeve joint in the chords.

The horizontal reactions of the wind strains, at each end of the centre span, are carried through the sleeve joints of the chords. The slotted chords, while allowing sufficient movement for changes of temperature, check any excessive movement from longitudinal strains produced by the wind or brakes set on a train.

The paper contains some very interesting notes on the deflection of a cantilever, the determination of which is of much practical importance to the builder in determining the lengths of members in the finished structure, in order that when built, the roadway may be level or have the desired camber.

As examples of how necessary it is to consider the deflection:

Under dead load only, the end of the 240 ft. arm of the Lachine Bridge was calculated to have a deflection of 4.17 inches (as given in Mr. Moore's description of the Bridge); the end of the Fredericton Swing, Bridge 122 ft. arm, when open, was calculated to have a deflection of $1\frac{5}{8}$"; that of the Murray Canal Swing Bridge 75 ft. arm—$1\frac{5}{32}$".

That these calculated deflections were correct was proved by the bridges having the desired cambler when finished, the calculated deflection having been provided for in the framing.

The formula that was used in ascertaining the deflections given above appears to be simpler than the equations given by the author in the paper. It originated, as far as the speaker knows, in C. Shaler Smith's office, and is given by Mr. Moore in his description of the Lachine Bridge.

It is:—deflection of any point $A = \Sigma . \frac{u.l.s.}{E}$

u = coefficient of action of member = strain produced in member by unit hung at "a."

l = length of member in inches.

s = stress per square inch.

E = Modulus of elasticity.

Σ = Algebraic sum of these values for the several members.

Mr. T.C.Clarke. This excellent paper is the beginning of the literature of cantilevers, although the bridges themselves have been known for some years.

The author omits, however, to refer to the *first* cantilever bridge, that was built by the late C. Shaler Smith, member Am. Soc. C. E., over the Kentucky river, in 1877, and described in the transactions of the Inst. Civ. Engrs., No. 1574, Vol. 54, 1877–8.

In those days the word *cantilever** had not been applied to this kind of structure, but there is no doubt that this bridge is as truly a cantilever as either of those described by the author.

He also omits any mention of the cantilever bridge built by the undersigned and his associates over the Hudson river at Poughkeepsie, N.Y., last year, which contains the largest cantilever spans yet built—Plate IV.

The writer differs from the statement of the author that "where the span is very great the cantilever bridge generally requires less material than any other rigid structure of equal strength."

This is not true either in theory or in actual construction.

The author gives the real reason for the adoption of the cantilever system in the next paragraph.

One of the most important questions connected with the designing of cantilevers is to determine "the proportion which the length of the centre span is to bear to the rest of the cantilever."

The writer does not agree with the author, that the method proposed by him will "give all the desired information with sufficient accuracy for the purpose." He believes that the only reliable method is to assume certain proportions, and take out all the quantities from the strain sheets as carefully as if for a bill of material for purposes of construction; and having done this to vary the proportions and make a second estimate of weights, in other words, to find the required proportions by a system of approximations.

There would be no objection to using the plan proposed by the author to determine the proportions to be used for the first approximation.

The joint between the central span and the cantilever has been worked out in the Poughkeepsie bridge, in a perfectly satisfactory manner, and one much simpler than that adopted at the Indus bridge.

The joint pins between the central span and the cantilever play in oval holes. The play is prevented during construction by wedges.

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*On referring to the paper No. 1574, the writer finds that he read these words: "By this means the stone spans were reduced to 300 ft. each, one end resting on the abutment, and the other on the overhanging end, or *cantilever* of the center span."

Hence the sectors bear no difference between the cantilever and central span until they come to join them in the centre. Then they move the wedges so as to lengthen or diminish the space, until an exact fit can be made between the rivets and their holes.

After the joint is rivetted the wedges are struck away together, and the whole is left free to expand and contract by changes of temperature.

Mr. Findlay's paper gives evidence of careful preparation, of extended reading, and of familiarity with the theoretical and constructive questions involved, and it is a valuable contribution to the literature on the subject. Mr. Lindenthal.

His objection, however,—the denomination of cantilever bridges as continuous girders—does not seem to be well founded. Though their classification is of trivial practical importance, in a theoretical sense, it arises from the consideration that any girder, requiring for its stability a continuance of its structure beyond the supports, is a continuous girder. By girder we understand a structure giving only vertical pressure on the supports. The above classification is established in contra-distinction to the single girder, which requires for its stability no such continuance of its structure beyond the supports.

In every continuous girder we have to deal with end moments, and it is for their easier and more accurate determination on statical principles that so called hinges are used for fixing the points of contra-flexure, by cutting the chords or booms at certain points. It is this breach of continuity which appears to Mr. Findlay as a contradiction of the classification, and it is the wrong location of these hinges and the perversion from their proper use under the pretence of economy which needs our attention.

The convenience of hinges in continuous girders is two-fold; a theoretical one in the more accurate and reliable determination of the stresses, and a practical one in providing expansion joints in the metal frame. As an offset against these two advantages, none very decisive, there may result some decided disadvantages, which have not found the weighty consideration at Mr. Findlay's hands which should have been given them, and which the writer wishes to point out further on.

Mr. Findlay seems to assume that all cantilever bridges are as good or better than other truss bridges for long spans, and he more particularly gives two reasons for the adoption of the cantilever type in preference to other types for certain situations:—First, economy of material for equal strength as compared with other rigid structures: second, facility of erection without false works for the cantilever spans. It does not

follow that these advantages are peculiar to the cantilever, because they can in the same or greater degree also be obtained with continuous girders without hinges, or with arches erect or inverted, according to local conditions. It is evident that Mr. Findlay treats his subject on the assumption that economy of material and of erection should be the leading considerations in the design for a cantilever bridge. But, from the standpoint of the bridge user, it must be observed that other features besides economy in the design have a great and superior interest.

Every bridge type has its advantages and its faults, varying in degree in different cases, and according as they are balanced in any given case to meet the conditions mentioned further on, so will result the design best suited to all the circumstances. The advantages of the cantilever bridge, more particularly the kind having two hinges in the middle span, have been stated by Mr. Findlay, not so their faults. In the following, the designation cantilever will be used as more particularly meaning the arrangement with two hinges in the same span.

DEFECTS OF CANTILEVERS.

The principal faults of cantilever bridges as they have been built are want of rigidity, and excessive and irregular deflection under passing loads. The euphonious name given to this type has probably had a good deal to do with its popularity. Had it been named more properly the "kicking lever bridge," it might have found less favor. Unless the dead weight of such a bridge is several times heavier than any live load that can be brought upon it, it will deflect too much to allow of the regular fast running of trains. For a waggon bridge there can be no question as to its being the worst type that can be chosen for comfort and usefulness. The question of deflection is of little significance in ordinary truss bridges, even of the longest spans (say 540 feet) yet built. It is rare that any previous calculations are made for it in ordinary practice, so that engineers may have easily overlooked the necessity for such investigations in the case of cantilever bridges.

Mr. Findlay rightly calls attention to the meagre treatment of the question of deflection and deformation of bridges in works on the subject. Yet it too often happens that the formulæ deduced for the solid beam are used for calculating the deflection of framed trusses with misleading results. The only correct way to find the deflection is by taking into account the change of length in each member, as Mr. Findlay recommends, which been made use of, for instance by Prof. R. Krohn in Germany, for the calculation of braced arches. That the

question of deflection is of more consequence in cantilevers than in other bridges, not only for its amount, but also and especially for its nature, will be clear on a little reflection. A beam suddenly loaded will deflect and then spring back. If supported at both ends, the greatest deflection is at the middle where the bending moment is greatest. If supported at one end, like a cantilever, the greatest deflection is at the free end where the bending moment is zero. It is important to keep this distinction in mind.

In the first case (beam on two supports) the springing back is resisted by the stiffness and weight of the beam greatest at point of greatest deflection. In the second case the springing back is resisted by less weight and least stiffness of the beam at point of greatest deflection. The result is a greater amplitude of vibration and of longer duration.

To appreciate the effect, reference may be made to a paper by Prof. S. W. Robinson (Trans. Am. Soc. Civ. Engrs., 1887, Vol. XVI, No. 351), in which he gives some indicator cards of vibration on ordinary truss bridges under different trains. (His arguments and conclusions based thereon however, appear to the writer erroneous). The indicator cards are valuable as showing one thing, previously noticed also by other experimenters, viz., that under fast trains the initial deflection of ordinary spans is nearly twice as great as the subsequent deflection, which more nearly corresponds to the calculated, or, say, normal deflection.

The obvious conclusion is, that the strains corresponding to that greater deflection must likewise be greater. Without going into an investigation of the proximate cause of this fact, we must notice as very important in this connection, the proportion of dead to live load strains. If for instance, they should, as per calculation, be in the normal proportion of one to one in any member, then the sudden loading will cause the proportion to be as one to two. If they are normally as one to two, for sudden loading they will be as one to four.

Now in the cantilever type we have this fact that the ratio of live load strains is greatest at the end. Hence the initial effect of a sudden load strains the members there proportionately higher, and necessarily the initial deformation must be relatively greater there than near the supports, besides being absolutely greater than the normal deflection, perhaps twice as great. As the structure tries to recover its normal position under the load and the cantilevers spring back, they do so with increased force, which at the ends is not resisted by any great weight or stiffness of structure. The effect is that peculiar kicking motion observed in a jumping plank.

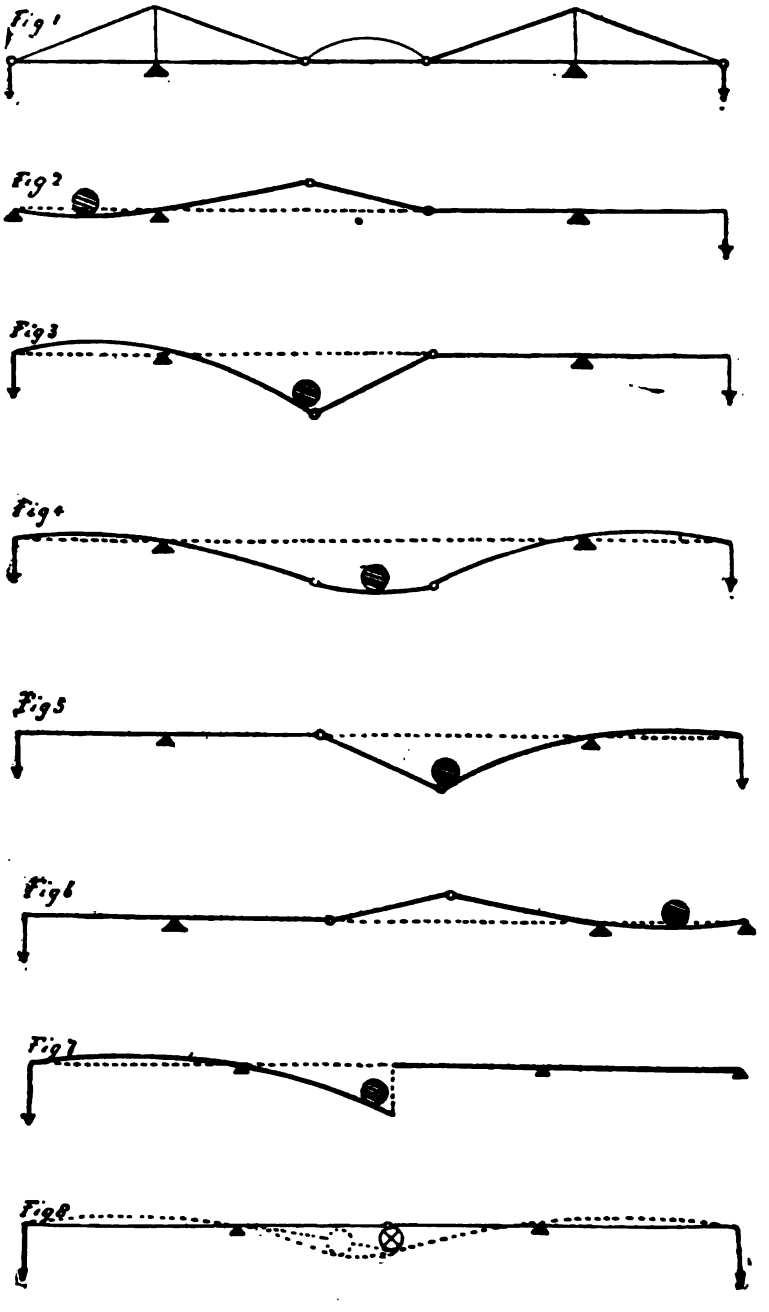
Fig 1
Fig 2
Fig 3
Fig 4
Fig 5
Fig 6
Fig 7
Fig 8

We have here then the explanation of a deflection, detrimental to rigidity of structure, and detrimental to the fast running of trains, unless the stresses from dead loads are much larger than from live loads in the cantilever ends. But the action of a rolling load, though bad enough at fast-train speed, is smooth in comparison with the action of trotting teams. The springiness and swaying of cantilevers becomes particularly noticeable and disagreeable on a waggon bridge.*

To further illustrate the importance of this question, observe the line of deflection of an ordinary beam and a cantilever beam.

For the beam it is uniformly concave towards the load, though changing for different positions of load with the maximum deflection at the centre. The reactions, whatever their value, take place simultaneously. The swaying of the structure ceases when the load has passed it. Not so in the cantilever arrangement, Figs 1 to 6. The curve of deflection is here not uniform; it changes in the shore arm from a concave to a convex form as the load passes over and beyond it. The curve is convex in the cantilever arms, having the slope of deflection increased by the convexity of the curve in the shore arm. There are successive violent changes of deflection in a broken line, the reactions from the load do not take place simultaneously on both supports as in the ordinary beam (or in a different degree as on a continuous girder proper), but they occur at different times and with greater variations.

The longer the cantilever arms and the shorter the suspended middle truss, the greater are the variations in the reactions, and the greater are the irregularities in the deflection. These we must regard as defects, and they are peculiar to this kind of bridge and to no other. Assume that the middle span would consist of two cantilevers meeting in the middle, but not connected there, Figs. 7, 8. It will be seen that a load could not roll over it at all, since the step formed by the deflection of the loaded arm would not permit of it. If these arms are connected with a sliding joint the problem is changed. It becomes a continuous girder hinged in the middle, which cannot be calculated on statical principles. This form of cantilever bridge, though not very commendable, is, however, more rigid, because reactions take place simultaneously on both supports for any position of the load on the middle span.

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* The market bridge in Philadelphia for instance is a heavy wide cantilever structure. All the same, a light single horse team sets the bridge kicking. It is safe to say that the same or a less amount of metal disposed in a different way would have made it a very rigid structure.

The defects of the cantilever with long arms, as now generally built, become aggravated for two or more tracks on the bridge by the uneven deflections of the trusses. The truss nearest to the lower track will deflect more than the other. As there is generally cross-bracing between the trusses, the heavier loaded truss will turn round the less loaded truss, producing a lateral motion. The lateral bracing between the trusses will be strained more than it would ever be strained by the wind, for which it is proportioned. Sometimes these cross rods may snap from the excessive strain put on them unnecessarily.

The worst position of trains for the bridge is when one has just reached the end of the cantilever, while a train on the other track is leaving it, a not infrequent event on a much travelled bridge. The raking motion of the structure resulting thereform is another grave defect. It is better practice to leave out the cross-bracing, save over the piers, and to depend on a very rigid and well designed lateral bracing between the top and bottom cords, which will permit the trusses to deflect independently of each other.

In a bridge with several long spans the cantilever arrangement can be used only in every other span. The material saved in the cantilevers is nearly used up in the connecting spans for the heavier web members and chords. The only advantage remaining to the bridge builder is the possibility of erecting every other span without false works.

The so-called five-hinged arch of Mr. Charles Bender, which Mr. Findlay mentions, does not seem to offer any improvement in point of rigidity or deflection over the ordinary two-hinged cantilever truss though on the point of economy it will give better results, provided the local conditions are favorable, either for cheap anchorages or for cheap abutments, to take up the horizontal forces without great extra expense. It is evident, however, that it could not be used in a succession of more than three spans, including two end spans.

When anchorages are used, instead of flanking spans for cantilevers, the economy as pointed out by Mr. Findlay (and also by Mr. C. Bender) can become very important where local conditions are favourable, particularly where the flanking spans would otherwise be over dry ground. But the same feature is applicable to continuous girders just as well without as with hinges, and in fact has been so used.*

* Such a structure for instance is the lattice bridge for single track railroad and wagon road over the River Kenzig in Offenbury, Germany, built about 1870, one span 210 feet. The ends project over into the abutments and are anchored down not so much for economy as for rigidity. The deflection is less than ½ in. under a passing train.

PROPERLY DESIGNED CANTILEVERS.

The most favorable arrangement of cantilevers for rigidity is obtained by placing the hinges coincident with the location of the points of contraflexure in a rigid continuous beam fully loaded. The original reason for such arrangement was the calculation of the type on statical principles, with only a small sacrifice of the most excellent quality of continuous girders, namely, rigidity and compactness.

The most notable instance of such an arrangement is the Kentucky River Bridge, built in 1876 77 by C. Shaler Smith on the Cincinnati Southern R.R. It was the first cantilever bridge built in America, and it must still be classed as the best designed of all that have been built before or since. Trains can and do run regularly at high speeds over the Kentucky River Bridge, without detriment to the structure, and without unusual oscillation.

If we take the Niagara cantilever bridge as the best of that class, more particularly treated by Mr. Findlay, and compare the observed deflections under the official test loads on the same with the official test of the Kentucky River bridge, the difference in rigidity will be explained.

The greatest observed deflection in the Kentucky River bridge at the hinge was $1\frac{1}{16}$ in. down and $1\frac{9}{16}$ in. up, or together a movement of $3\frac{1}{2}$ in. In the Niagara bridge the similar results were $7\frac{3}{8}$ in. down and $1\frac{3}{4}$ in. up, together $9\frac{1}{8}$ in., including the effect of the shortening of the towers in both instances. The maximum deflection at the middle of the Kentucky River bridge was $3\frac{7}{16}$ in. The corresponding total movement in the Niagara Bridge amounts to $9\frac{1}{2}$ in. In the Kentucky River bridge, the line of deflection is smooth. In bridges of the Niagara type it is very much broken and angular. The breaks in the line of track, though small and hardly noticeable at low speeds, cause, at high speeds, shocks and very marked swaying. These could be avoided if cantilevers were built rigid and compact with a view to minimum deflection.

Can it be maintained that economy of material and erection are the principal things to be considered in a bridge design? If so, why in certain cases should a suspension bridge, carrying merely the floor without any stiffening frame, not be the most desirable bridge on the score of economy of material and ease of erection? It could not fall down, and its curve of deflection has not the violent angular irregularities of the cantilever. The answer must be that it would not be rigid enough. The same reason holds good for the cantilever. The hinges should not be pushed out too far from the supports to gain an improper and un-

important economy of material, without regard to the impaired usefulness of the structure. It is a perversion of a useful device.

The Forth bridge now building in Scotland should not be taken as an example, since there the cantilevers are long from necessity, and compensated for by the great height of the towers. The low clear head room near the shores is a feature rarely obtainable over large navigable rivers.

CONDITIONS FOR GOOD DESIGNS.

The notion that the highest aim of the bridge engineer should be greatest economy of material and low cost is erroneous and liable to lead to costly mistakes. It is as difficult to formulate rules for sound judgment in bridge building as for anything else, let there be issued ever so many extensive and complicated specifications. But we hold that the following conditions should be complied with in the design for a bridge, particularly for a large bridge:—

1. Judicious accommodation to local conditions of shore formation, of foundation, of navigation interests, crossings, approaches, &c.

2. Rigidity and compactness with a view to durability under high speeds for trains.

3. Simplicity of manufacture and erection.

4. Architectural appearance to give dignity and character to the structure.

5. Satisfying all the above conditions, there must be economy of material and easy erection at low cost.

There are few large bridges in this country in which all these conditions are complied with. Mr. Findlay gives prominence only to the third and fifth conditions, probably assuming the others of no great interest. It has become the rule rather than the exception to sacrifice everything to so-called economy, taken to be the lowest possible first cost under some specifications.*

*A refinement in dimensioning of bridge members is affected in some specifications under the pretence of scientific economy and precision, which gives astonishing and absurd results. For instance, of three important roads one will get its plate girders with top flange heavier than the bottom flange. The next will get just the reverse, and the third will have both flanges alike. Yet each strenuously maintains that he is right and the others wrong. Many instances of such senseless differences in specifications could be cited, all of which goes to show that we have not arrived yet at the point where we may dispense with a liberal factor of ignorance.

Rigidity is considered as only an incidental matter, instead of a cardinal condition. It is rarely specified or insisted upon.*

Architectural considerations are not only neglected, but more hideous looking structures it would be difficult to design on purpose. The economy of long slender cantilevers is of as little account as the economy of inadequate stiffening trusses in suspension bridges. In both cases travel can pass over with safety only at low speeds.

CANTILEVER CONTINUOUS GIRDERS.

As remarked above, the advantages of economy of material and erection without false works are not peculiar to the cantilever truss among girder bridges. There is the continuous girder proper, which has been more frequently used with success on continental railroads. It can likewise be erected without false works by building out cantilever fashion, where necessary. Where the foundations are on rock, uneven settlements of the supports are precluded, and the first condition favourable to that type of girder is obtained.

The most notable instance of such a construction is the Lachine bridge, at Montreal, over the St. Lawrence River. In the case of high metallic towers, which cause temperature strains in continuous girders, these can be proportioned for them. The economy of continuous girders has been frequently disputed, more particularly as compared with the American pin-connected single span bridges, but such comparisons have been based on arbitrary assumptions.

Most of the utility structures in this country with which these riveted bridges have been compared have already been rebuilt, while the old continental lattice girders are still existing in as good condition as when they were built.†

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* Of the importance of that condition, and of the little attention paid to it, there are many instances. To name only one there is the Kinzua Viaduct in Pennsylvania, built in 1883, the highest iron viaduct in the world (285 feet high). Its construction was in accordance with what is yet considered a very good bridge-specification. Still the great structure is found to be swaying so much under trains, at 4 miles per hour, that its rebuilding or abandonment is considered a question of no distant time. High iron towers unless built very rigidly are subject to the same kind of swaying from lateral forces as cantilevers.

In this connection we may notice, for instance, in the Forth Bridge, in Scotland, the bracing of the tension members a well considered feature for rigidity and durability.

† On some important railroads, iron bridges have been rebuilt two and three times in 25 years. Each time an advance was claimed on the former prac-

Continuous girders are usually built with parallel chords, though their chord lines can be varied as well, and for very long spans it may be an advantage to increase the height of the trusses over the piers, only one of which could be provided with a fix bearing for the truss. The absence of expansion joints in the trusses is an advantage rather than otherwise; it is conducive to stiffness and compactness, and it is preferable to place them at both ends of the structure, hinged or not, even if it should be several thousand feet long; as witness the rigid Kentucky River bridge, and swaying bridges of the Niagara type.

CANTILEVERS WITHOUT HINGES.

The objection to the tedious calculation of the continuous girder proper is of little importance, as compared with the great practical advantages gained, where the local conditions are suitable for the type. But there is one kind of girder which offers all the principal advantages without this objection. This is the continuous girder with fixed pier moments as first used by the writer. The principle of this girder is based on the fact, that with the pier moment known, all other stresses become determinate. These pier moments are chosen at will, for the best disposition of material in the trusses, and they are constant. The trusses are not affected by the uneven settlement of the piers since the pier moment can automatically adjust itself to it.

A permanent and known tension in the top chord, or a permanent and known compression in the bottom chord above the pier, artificially produced by means of any convenient funicular lever, or wedge arrangement, furnishes the desired pier moment to order, as it were. Usually it will correspond to the dead load of half the cantilevered truss, but it can be chosen greater if desired. The calculation is made on statical principles. To the cantilever stresses corresponding to the chosen pier

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tice. On the other hand, there are some remarkable instances of longevity in the old iron close meshed lattice bridges. Perhaps the most notable one is the Allegheny River Bridge of the Pennsylvania R.R., in Pittsburg, about 1100 feet long with seven through spans, about 160 feet each, three trusses for double track discontinuous girders, built in 1864, and of rather indifferent workmanship. There were several accidents with cars and locomotives off the track, without the trusses ever giving way. It has outlasted almost every other iron bridge of the same age on the road, and with few repairs can be made to outlast another generation of iron bridges. The idea that the heavier rolling stock of the present day is wearing out old bridges is here disproven.

It would be heresy now-a-days to propose such a construction, but the type is capable of great improvement, and it certainly makes a durable bridge.

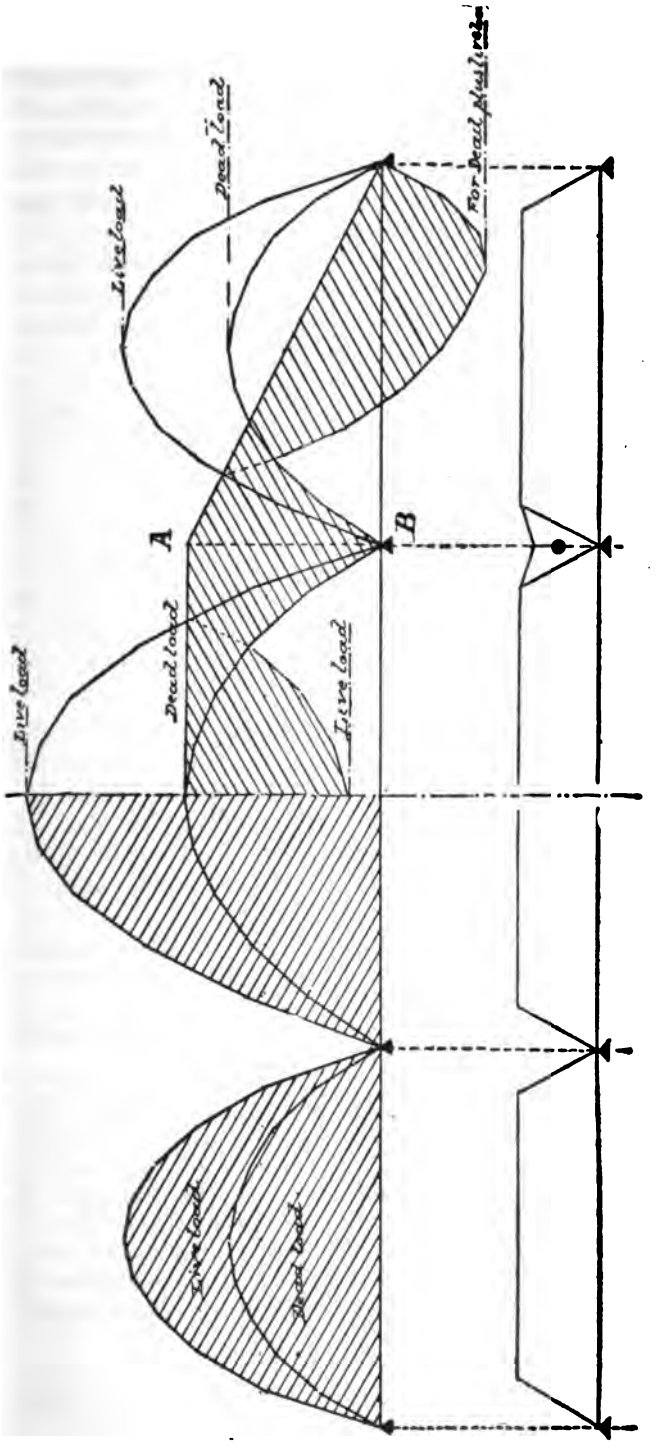

Live load
Dead load
Live load
Dead load
A
B
Live load
Dead load
For Dead Moment

Fig 9

moment, add algebraically the live load stresses as calculated for a single span truss. Such members as are exposed to both tension and compression are proportioned only for the strain requiring the larger section, which is properly assumed to include the section for the opposite strain.* But the rivetted splices in the chords are proportioned for the numerical sum of both stresses.

It will be understood from the annexed diagram, Fig. 9, that the greatest saving of material is again in the chords. As the left half of the figure represents in the shaded portion the amount of material needed in the chords, so the right half shaded likewise represents the amount and distribution of material in the chords for a continuous girder with fixed pier moments, which for brevity may be named the *moment girder.*

These diagrams are made on the assumption of a uniform distributed load in both cases, and with the material for the web-members unchanged. In practice, however, the material for the web-members of the moment girder is considerably smaller, because of the smaller dead weight in the trusses; and this dead weight is not uniformly distributed but is greater near the supports. When the pier moment corresponds to half the cantilevered truss, the web strains from dead load are the same as if there were no pier moments, or the same as in a single truss.

In this there is an economy over the usual continuous girder, in which the web as a rule will be heavier than in single girders, so that all the saving is from the lighter chord sections alone. The saving is thus not only in the chords but in the web-members also.

An illustration of the economy as compared with the usual cantilever type may be had from two strain sheets hereby annexed. (Plates V and VI.)

Fig. I is the strain sheet of the Niagara Bridge, thought to be the most economical type for that place. (Schneider on cantilever bridge, Trans. Am. Soc. Civ. Engrs., Vol. XIV, No. 317.)

Fig. II is the strain sheet for the same specifications of a moment-girder.† The comparison results as follows:—

* The correctness of this rule has been disputed, and in fact, not a few bridge specifications prescribe the adding of the sections for alternate strains That this view based on Woehler's experiments for quite a different purpose is wrong for strains within the elastic limit, has been clearly demonstrated by Mr. Bricka and others.—(Annales des Ponts et Chaussées, 1888.)

† The writer does not wish to be understood that he would have advocated continuous girders for this place, though such could with the same facility have been erected without false works. Of all places the Niagara

The Niagara Cantilever Bridge, as built, contains 2246 tons of steel and iron. 2246 tons

The continuous girder with fixed pier moment 1998 "

Saving 248 "

The weight of the floor construction, towers, anchorages, wind and cross bracing are the same in both designs. The saving, therefore, is all in the girders, and amounts to over 12 per cent. of the total weight of metal in the bridge. The comparative weights are graphically represented in Figs. III. and IV, so as to show the difference in distribution of the weight and material.

There would have been the additional advantage with moment girders of a rigid structure for fast trains.

The calculated deflection of the girders would have been $3\frac{1}{2}$" against 8" in the cantilever bridge. *

A comparison with other like cantilever bridges would show a similar great economy of material, as well as a more rigid structure. The deflection from live load alone of a moment girder is the same as for a single span girder. There is no bending upwards as in the shore arms of the cantilevers, or as in the usual continuous girders. There is greater compactness of construction, top and bottom chords being rigid.

A comparison of weights for a 540 ft. continuous girder of this system with a discontinuous girder, both calculated for the same specifications, is here given as taken from one of the writer's designs Fig. V. The discontinuous girder is assumed to have a height equal to $\frac{1}{8}$ the span, while the height of the moment girder is only at 1-10 the span, on account of the flanking spans.

Total weight of iron and steel in moment-girder span is 894 tons.

For the discontinuous girder span 1085 "

Saving 191 "

or nearly 18 per cent.

River chasm was the place for an arch bridge. Not only had nature provided the abutments, but architectural considerations would have been better satisfied at no greater cost by an arch bridge somewhat on the plan of the Garabit Viaduct in France, which was erected without false works. It would, however, have required more time for building, which, it is understood, was the main consideration for the choice of the type for the Niagara Bridge.

* It was found necessary to reduce the speed over the existing structure on account of the swaying, to nearly the same slow rate as over Roebling's old suspension bridge near by, namely, to about four or five miles per hour.

It is understood that continuous girders are properly used only for three or more consecutive spans. A favorable proportion of the end or flanking spans to the middle spans is as 8 to 11, but the saving, compared with single spans, is very decided also for much shorter end spans. As an instance of cantilevering such a bridge, the annexed photograph will be of interest as showing one-half of the 30th Street Bridge in Pittsburg during erection. It was first erected on false works, but these were swept away by a flood, leaving the bridge in the position shown, with one-half of the middle span cantilevered out. It saved the middle span. The pier moments are produced by a simple funicular arrangement in the top chord eyebars above the piers, weighted down with a loaded lever under the floor. It is readily accessible for inspection. A strain diagram is on the annexed sheet, Fig. VI.

The bridge has wooden floor beams. The total weight of iron in all three spans is 322 tons, not including the heavy iron hand railing. Under the same specifications for discontinuous girders, the weight would have been 430 tons, shewing a saving of 108 tons, or nearly 25 per cent. The bridge is so rigid and compact that teams are permitted to cross it with trotting horses. This could not have been the case for discontinuous girders, except by making them stronger for heavier specifications.

A notable application of this system of continuous girders is proposed for the Detroit River Bridge at Detroit, Mich. The three spans over the River are intended to be 800, 1100 and 800 feet long and 150 feet above the water. The middle span is to be erected by cantilevering without false work. The calculations and estimates made show a most remarkable saving in material, as compared with any other system of bridging under the given conditions. The pier moment is to be produced by a loaded wedge inserted in the bottom chord, and arranged for the small movement to which it is subject, with due regard for the friction and the consequent small variations of stresses. These variations are no greater than in a single span bridge, in which the length of the bottom chords for instance is changing under stress, causing a movement of the roller bearing, the friction of which is rarely taken into account in the calculation of the stresses.

A tentative design for a bridge over the North River at New York City, having two middle spans of 1400 feet each, with the same system of continuous girders, again showed in comparison with other truss designs made for the purpose, the same great advantages and economy. It is plain that neither a cantilever on the middle pier nor a suspen-

sion bridge of two consecutive spans could in this case be contemplated for heavy concentrated train loads.

The continuous girder without and with hinges have this in common, that a live load on one span affects the adjacent spans. Not so in the moment girder. This is affected in the same manner as the discontinuous girder. The live load in no way affects the adjacent spans. That with the advantage of a statically determinate construction, not affected by uneven settlement of supports (as is the ordinary continuous girder), there is in the moment girder the same if not greater economy as with the former type, is shown by a comparison in a strain sheet hereby annexed, Fig. VII. It is for that combination of deck and through spans, as in the Lachine Bridge at Montreal by the late C. Shaler Smith, and as published on the subject. (For want of time C. Shaler's strain sheet is here not copied, and it is assumed that it is in the hands of most Bridge Engineers.)

An estimate of weights for the moment girder gives 82 tons less weight, namely, 2074 tons for the continuous girders of C. Shaler Smith, and 1192 tons for the moment girders, a difference of about 4 per cent. in favor of moment girders. The difference would be somewhat greater, if the dead load had not been assumed equally distributed (to preserve same basis for comparison on assumed data with C. Shaler Smith's design). As a matter of fact, the greater proportion of dead load is near the middle three of the five supports for the continuous girders. The curving down on the chords at the middle support makes little change in the weight of metal, though it saves some masonry. Pier moment for such construction is produced by a simple wedge arrangement above the piers. On another occasion the writer proposes to treat of this type more fully.

The comparisons are made merely for the purpose of emphasizing the statement, that hinged cantilever bridges forming spans are neither more economical in material than others, nor the only ones that can be erected without false works. For short spans they must be rejected altogether. Since Mr. Findlay mentioned these features as the most conspicuous advantages, and by his able treatment of some of the economic conditions for designing cantilevers might convey the impression that they are of greatest importance, the writer has endeavored to point out that other more important conditions must also be fulfilled in a good bridge.

Bridges have become an article of fabrication, very much like steel rails. It requires no skill or knowledge of the art on the part of a Rail-

road Engineer, who, as a rule, is quite able to select such bridge as under some specifications he can buy cheapest. There are even some roads where the buying of bridges is done by the purchasing agent of all supplies nearly quite as well. As a rule the road will in this way get a safe bridge; whether it is rigid and durable or not is apparently a minor question for most new railroads; but it should not be so for older and conservative roads, or in the case of large and important structures.

The ugly swaying cantilever bridge of the present day, and as built in this country, is unfit for fast trains or for hard usage, and should not be built where the cost is so high as to put early rebuilding out of the question.

No universal rule can be laid down for good bridge designs. For the present method of bridge letting and buying, we can at most make specifications to prevent unsafe bridges. In the competition for bridge work in vogue, the bridge builders cannot be blamed for a rigorous interpretation of specifications, and the structures resulting therefrom. The interests of the bridge builder and the bridge user are not identical. Still the builders are not only required to bid for the manufacture and erection of the structure, but also to furnish the cheapest design under a set of specifications, which, if they should provide for everything of advantage or necessity in a good bridge, would have to be enlarged to the size of a text book. It has been found already to be a doubtful economy on some railroads, and it is probable that this practice will change, as our experience enlarges, to a more rational and satisfactory method of obtaining durable structures.

Mr. C. Findlay. The writer is much gratified that his paper has elicited such a valuable discussion. It did not pretend to give a complete account of the subject from any point of view, but only to direct the attention of students to some of its noteworthy features.

He had no intention of entering upon the respective merits of cantilever and other bridges. This is a very large question as to which a superficial treatment or a bare expression of opinion would be of no value, and he ought to have assigned as one of the reasons for building cantilever bridges a *supposed* economy of material, instead of stating that such an economy could be realised, for the sake of avoiding a statement open to question which he had not space to give his full reasons for. He thinks, besides, that while the study of such questions is of the utmost importance, it is the methods that are valuable rather than the results. The problem of the engineer is not to build a bridge between any two given points A and B, as in the books, but to deal with a particular

site, under specified conditions; and the circumstances of different large bridges vary so much, that no mathematical investigation can possibly take account of them all. The writer's own view is that on such important questions no engineer would be justified in practice in accepting a conclusion or formula, in which he had not carefully adapted the hypotheses and proof to the case in hand, and if possible, verified its application by actual weights taken from drawings.

The writer is unable to accept Mr. Bender's limitation of the definition of a cantilever bridge, as stated by the writer. The difference is simply one of nomenclature. The importance of the distinction he draws between two classes of bridges is sufficiently obvious, but it is not typical and should not affect the classification. The girders of the Victoria Bridge at Montreal would still be called "tubular" if they had been built over dry land, and in the same way a cantilever remains the same thing and should be described by the same name, whether its use in certain cases is justifiable or not. The term continuous girder should, in the writer's opinion, be reserved for girders which are continuous over 3 or more piers, that is to say for those whose equilibrium is statically indeterminate, and which require the application of the theory of elasticity in some form to determine the stresses in them. This would be more consistent with ordinary usage than Mr. Bender's definition, and expresses a distinction which is far more necessary to emphasize from a scientific point of view. A continuous girder in which the continuity has been destroyed is, in the writer's opinion, a contradiction in terms.

In speaking of the weight of anchorage material to which Mr. Bender refers, the writer used the phrase to indicate only the weight necessary to resist the pull of the guys or backstays. In considering the most economical angle for the backstays, if the material in the post at the abutment on which the backstay presses be also taken into account (as he admits should be done), then the depth at which the backstays terminate becomes an element in the question. The quantity of metal necessary is only independent of the depth of the cantilever in the particular case when the backstay terminates on the horizontal plane through the foot of the post, and the angle given by Mr. Bender seems to be determined for the same particular case. The configuration of the ground and the nature of the anchorage will never be alike in two cases, and must be taken into account in determining the most advantageous arrangement. The same remark applies to Professor Burr's question as to the proportion of the shore arm of a cantilever bridge

such as the Niagara. Correct methods of the mathematical investigation of these questions are indispensable, but general results should be applied with caution to particular cases.

Mr. Bender remarks: "That he fully agrees with the author as to the importance of secondary strains. But who has ever undertaken to calculate them for a bridge with cantilevers of varying depths?" This seems to imply that the writer has recommended such an undertaking; but he did not mean to convey any such idea, and will briefly explain again the line of his argument on this subject. Secondary stresses in a girder are the result of the changes of figure (or "deformations," as he has called them for brevity) resulting from the primary stresses. The task of calculating the secondary stresses is too formidable to be undertaken, but the deformations can be approximately ascertained by the simple graphic process described. The information thus available does not enable the secondary stresses to be numerically determined, but conveys valuable information in regard to them. For instance, the marked effect of varying the arrangement of web members without altering the booms is in some cases most striking, and the joints at which secondary stresses will become most severe and where, therefore, hinged connections are most desirable can be seen.

The formula for deflections $\Sigma \frac{u.l.s}{E}$ given by Mr. Duggan is neat and convenient in form, though in application it would not be more rapid than the equations the writer has given. It is identical with those equations except for the web members of a cantilever varying in depth, and for them it is not correct, as may be easily seen by applying it to the case of a triangular cantilever whose depth at the end vanishes.

In that case u is zero for all the web members, but the deflection due to strain in the web members individually is not zero. It may have a considerable value and may be negative, *i.e.*, the effect of strain in some of the web members of such a cantilever taken by themselves may be to raise the end of the cantilever.

It is perhaps worth mentioning that this question of deflections and secondary stresses assumes greater importance from the increasing use of steel in place of iron, and with it higher working stresses. The higher coefficient of elasticity of steel compensates for this to some extent, but by no means entirely. The higher primary stresses give a larger strain (elongation or compression) of each member, thereby causing greater general deformation of the figure of the framework and larger secondary stresses.

Mr. Clarke has commented on the method proposed by the author for ascertaining the effect on the weight of a bridge by varying the proportion of the centre span to that of the cantilevers. If it can be used for a first approximation, its use for that purpose would be well repaid, because it tells a great deal more than merely what proportion gives the absolute minimum of weight. It will show the effect on the total weight of varying the length of the centre span, over the whole range for which the table is compiled, and as there are generally other considerations to be regarded besides quantity of material, this information may be of great service. To make complete drawings and bills of quantities for so many designs would often be impossible within the limits of time available. Of course any such method requires to be applied with great judgment, and its results should be verified by comparison with actual weights from completed designs. If such a comparison were made for one or two of the proportions used in the table and found satisfactory, the rest of the table might be accepted as approximately correct; if not, the source of error in compiling the table should be sought for by comparing its elements with the corresponding actual quantities and the requisite corrections made throughout the table.

One correction is necessary in the paper; the method of connecting the centre span of the Indus Bridge to its cantilevers has been altered since the paper was written, in favour of a plan similar to that recommended in the paper, using a vertical pin on the centre line of the bridge at one end of the centre span.

Mr. Bender takes exception to the author's advocacy of a variable depth in a cantilever on the ground of economy. Having studied the argument on this subject in his book with the care it deserves, but without being convinced by it, the author thinks the error of supposing that a uniform depth leads to the greatest economy of material can be shown by a very simple reductio ad absurdum.

Accepting that doctrine for the sake of argument, let it be supposed, for the sake of simplicity, that the economical depth for a certain type of construction is in a simple proportion to the length of the cantilever—say $\frac{1}{5}$th. Thus, the most economical cantilever 200 ft. in length to carry a given distributed load, and also a given concentrated load on its end would be of a uniform depth of 40 ft.

Take now a vertical section 100 ft. from the abutment, and consider only the portion between this section and the end. This portion is itself a cantilever 100 ft. long. All its stresses and conditions are exactly the same as if it rested on an abutment, instead of being supported by the remaining portion of the cantilever.

By the same law assumed above, therefore, its weight would be reduced by diminishing its depth from 40 ft. to 20 ft. which is $\frac{1}{8}$th of its length. Applying the same argument to each portion of the cantilever, we see that the assumption of a uniform depth of $\frac{1}{8}$th as the most economical, logically leads to a uniformly varying depth of 1 to 5 as the more economical still.

Of course there is no reason to suppose that the greatest theoretical economy would be realized by making the depth vary with the length in a simple ratio. The proper depth, if ascertainable, is probably a more complicated function, depending in a very great degree on the type of construction.

Mr Lindenthal evidently supposes that the author is a champion of cantilever bridges as against other types of construction. Nothing can be further from the fact. In three out of the four instances of cantilever bridges quoted as illustrations, a very fair case can be argued for some other form instead of the cantilever. Cantilever bridges are undoubtedly the fashion, and the author was asked to furnish some notes on their design.

He started therefore by supposing it had been decided to adopt that type, and purposely avoided the much larger question, which can only be usefully discussed in connection with a specific case or cases. Mr. Lindenthal also presumes rather harshly, that he is indifferent to every consideration to which he has not expressly referred. The paper might have been many times longer, and still left him open to a similar charge.

In most of Mr. Lindenthal's remarks on the deflection of cantilevers he concurs, but with some qualification. A cantilever bridge will undoubtedly give a larger deflection in most cases than a truss bridge of the same span, but it does not necessarily follow that it makes a worse bridge for that. Deflection is not an evil in itself, however large it be, but it may be either an indication or a cause of over-stress which is the evil to be guarded against. To determine whether deflection is injurious or not it is necessary to separate the statical deflection from the dynamical or the deflection under a quiescent load from that due to the same load in movement. The statical deflection is or ought to be that which corresponds to the statical stresses for which the bridge is designed; and if those stresses are not exceeded, the author does not see what evil there is in large deflections (within, of course, reasonable limits). With dynamical deflection the case is entirely different. Its probable amount cannot be foreseen in the present tate of our knowledge, and we know very little as to what other

ill effects it may cause besides the additions to the statical stresses that must accompany it. It depends on the manner of application of the loads as well as on the character of the bridge. Its importance has been recognised ever since iron bridges have been built, but definite experimental information is very scanty, and Professor Robinson's paper referred to by Mr. Lindenthal is a most valuable contribution to our knowledge of the subject. Now of course Mr. Lindenthal knows all this as well as the author, but the latter thinks the indictment against cantilevers is too sweeping, because he does not in his remarks sufficiently distinguish between the statical deflection to which they are undoubtedly more liable than other types, and the dynamical deflection which may or may not accompany it to a dangerous degree. It does not follow because a particular cantilever bridge is subject to violent oscillations that the fault is inherent in the system. There are other cantilever bridges that are as steady as any truss bridges The relative amounts of dead and live load are important factors as Mr. Lindenthal says, as also the higher or lower stress per square inch allowed in the members, the general design whether tending to extreme lightness or otherwise, and other circumstances that vary from bridge to bridge. In Mr. Lindenthal's main contention however, that where a cantilever is likely to give an unstable springy bridge, it is for most purposes objectionable, most engineers will agree with him, and his warning against the neglect of rigidity and durability is perhaps more necessary in America than in Europe. In England our errors are generally regarded as lying rather in the opposite direction.

Mr. Lindenthal's description of his moment-girder, as he calls it, is most interesting and, to the author at least, new. It has obviously great merits, but one's first impression is rather to shrink from making the security of a bridge depend on a mechanical device which will require periodical attention. His reference to expansion rollers is scarcely a happy analogy, because if all the bridges provided with that luxury were dependent for safety on the rollers doing their duty, there would be a great many more bridge failures than there are. However, Mr. Lindenthal has, no doubt, a complete answer to this *prima facie* objection which he must have fully considered.

Mr. Whited's observations on the unwisdom of rivetting a straight and curved bar together, under the expectation of a fair division of stress between them, are very just but the writer can scarcely imagine any engineer adopting such a course. There is nothing in the Sukkur Bridge which he quotes, designed in that way, all the main members of that structure, so far as the writer knows, being symmetrical in form.

Thursday, 14th February,

F. R. F. BROWN, Member of Council, in the Chair.

The following having been balloted for were duly elected as

Members.

Morley Donaldson, Gustav Lindenthal,
Frederick James Leigh, Charles Macdonald.

Associate Members.

Joseph Phillipe Baby Casgrain, John L. Hislop,
Alexander Bell Ross.

Associates.

Marshall D. Barr, Edward B. Greenshields,
Hon. J. A. Boyd, Joseph Hickson,
Robert Cowans, Herbert Samuel Holt,
Michael P. Davis, John P. Mullarkey,
Richard R. Dobell, William Perry, Jun.,
Joseph Damien Fitzpatrick, T. Murray Swinyard.

Students.

Clarkson M. Canniff, Cornelius M. Murphy,
Emery Lafontaine, William C. G. Smart.

Paper No. 28.

THE DEVELOPMENT OF THE LOCOMOTIVE.

By T. T. Vernon Smith, M. Can. Soc. C.E.

A series of railway articles, have recently appeared, in a leading magazine, which have been decidedly interesting and deservedly popular, but they contain a number of statements which, designed to please American readers, are by no means correct in fact or generous to the engineers of other nationalities. Old country engineers have learned to regard railways and the locomotive, especially in its present form, as their undisputed invention and introduction, and although they are not so inconsiderate as to claim every individual improvement, yet they consider that in this one department of engineering, the great

bulk of the evolution of the present railway has been peculiarly British, and that Americans have not contributed a great deal towards the mechanical and scientific triumph that we now see. The first number of these papers is particularly guilty and ungracious in claiming for American inventors everything valuable and important that has been found out. "The modern railway," "was created by the Stephensons in 1830, when they built the locomotive Rocket. The development of the railway since is due to the development of the locomotive." "The earlier locomotives of this country modelled after the Rocket, weighed five or six tons, and could draw on a level about 40 tons. After the American improvements, which we shall describe, were made, our engines weighed 25 tons, and could draw on a level some sixty loaded cars, weighing 1,200 tons. The Stephenson type once fixed has remained unchanged (in Europe), except in detail, to the present day." "When we come to the United States we find an entirely different state of things. The key to the evolution of the American railway is the contempt for authority displayed by our engineers, and the untrammelled way in which they invented and applied whatever they thought would answer the best purpose, regardless of precedent." "When we began to build our railways in 1831, we followed English patterns for a short time, but our engineers soon saw that unless vital changes were made, our money would not hold out, and necessity truly became the mother of invention. The first and most far-seeing invention was that of the swivelling truck, which enables the engine to run round curves of almost any radius. This enabled us to build much less expensive lines than those in England, for we could avoid hills and other obstacles. The swivelling truck was first suggested by Horatio Allen for the South Carolina Railway in 1831, but the first practical use of it was made upon the Mohawk and Hudson Railroad in the same year. It is said to have been invented by John B. Jervis, Chief Engineer of that road. The next improvement was the equalizing beams or levers, by which the weight of the engine is always borne by three out of four or more driving wheels. The original imported English locomotives could not be kept on the rails of rough tracks." "Another American invention is the switch-back, by which the length of line required to ease the gradient is obtained by running backwards and forwards in a zigzag course, instead of going straight up the mountain. This device was first used amongst the hills of Pennsylvania over 40 years ago, to lower cars down into the Nesquehoning Valley." Now this is sufficient to shew the general style of

claiming everything that has led up to the present development of railways for American engineers only. Excepting to the Stephensons, not one particle of credit is hinted at as belonging to anyone else. Touching however the American invention of the switch-back, Mr. Curtis Clarke's claim of 40 years' use in Pennsylvania is not sufficient. In Tom Moore's Epicurean, written in 1800, a good 40 years before that again, is a capital description of the switchback, and by it the pretty priestess of the Egyptian temple saves the life of her lover. Tom Moore wrote some of his finest poetry, including Lalla Rookh and the Epicurean, in the heart of the lead mining district of Derbyshire, where the "switch-back" has been in use for a century, as a means of bringing the materials to the smelting works in the valleys. All that American engineers invented in this contrivance was the name, and as for some of the other claims that are inferentially supposed to have evolved the American locomotive and railway from the primitive rudeness of the English original, it may prove that the improvements rest upon an equally poor foundation.

In comparing English and American practice, especially in the earlier days of railways, one great source of confusion and mistake, made by American authors, arises from the fact that in England there have always been two distinct classes of railway, one chartered by Act of Parliament the affairs canvassed and discussed every half year, and all their peculiarities and inventions thoroughly ventilated by the papers and in other ways, whilst the others are strictly private, their proceedings, experiments and practices utterly unknown to the public, and but seldom finding their way into the public press. Yet these "private" railways preceded the public lines by years; until quite recently even their mileage was in excess of the public lines, and almost every important invention that has led to the result of the modern locomotive and the existing railway was invented, tested and developed on the private railways of Great Britain years before there was a mile of railway in America. The double trucked car for instance, which in the magazine is claimed as the invention of Ross Winans, was in use for carrying timber and long stuff before there was a road in America at all; and the passenger car out of which Mr. Huskisson descended to meet his death, on the memorable day that preceded the opening of the Liverpool and Manchester railway, was a double truck car much as we now see them, and what was more, it had seats with reversible backs, such as are now universal in America, though they were never commonly used in England. This identical car was

only used on the Liverpool and Manchester for a short time, and was subsequently sold to the Newcastle and North Shields, where numbers may still remember it as being occasionally used on the Sunday trains. The early history of railways begins altogether with the private unchartered roads of Great Britain, for although a railway company was chartered in the last century, and the first public railway that was actually constructed dates from the first year of the Nineteenth Century, all these early public roads were worked by horses, and contributed nothing of either scientific or mechanical interest until the Stockton and Darlington of 1825. During this quarter of a century, however, the private roads had solved most of the important mechanical questions upon which all the subsequent evolution of railways depends. Although the Mag. article speaks disparagingly of the results of all the experiments and investigations prior to the era of the Rocket, there were but few important points in railway practice unsolved at the date of the Rainhill experiments, either in the construction of the railway or of the locomotive. Since 1812 locomotives had been in constant daily use on a number of private railways, and these lines had been constructed and were being worked with just as rigid a regard to economy, and with as successful a record for economical work, as any of those subsequently laid down. The old Stockton and Darlington was laid out, not only with a strict regard to economy, but so as to make it the best and most perfect road that could be obtained between its termini, and it remains, to this day, as complete and finished a line as can be produced, nor is there in existence, as far as the author knows, anything very much superior to the old Quakers road, finished five years before there was a railway of any kind in America. Even the latest improvement introduced on the New York Central, for the advancement and recreation of their employees, might with advantage, take a leaf from the experience of the Stockton and Darlington 40 years since, on the management of the railway employees' reading, coffee and recreation rooms, which were the first to be introduced and are still perhaps the most successfully managed on this good old railway.

From Woods' "Treatise on Railways," the first edition of which was published in 1825, we learn that the date of the introduction of railways into the Newcastle district was between the years 1602 and 1649. These were entirely of timber. In 1738 cast iron rails were substituted for the upper stringer, which was made of hardwood and took the wear of the wheels. In 1747 the Colebrookdale Company replaced their wooden rails with cast-iron, and iron wheels were introduced in 1753. Tramplates of the section used by Outram had been

in use before his day, being first laid, it is supposed, on the Duke of Norfolk's railway near Sheffield in 1776, and the original shape was improved upon on the Surrey tramway, which has the honor of being the first public railway built under an Act of Parliament. This pioneer railway, which obtained its Act in 1801, extended from the Thames at Wandsworth, to Mersham and Reigate, being, with branches, 28 miles in length, and was subsequently sold to the Brighton Company and torn up. In 1793, Outram, from whom the tramway takes its name, laid down a number of tramways in Derbyshire, and introduced the stone blocks under the ends of the tramplates, which for a time displaced the former wooden sleepers, and were used by the Stephensons and others in all the early railways. The first edge railway, which is the parent of our present railway, was laid in 1801, for the conveyance of slate from Lord Penrhyn's quarries in North Wales, and within a few years all the Northumberland and Durham collieries adopted this improvement, and the railway superseded the tramway for ever. In 1789, Mr. Jessop constructed the public railway at Loughborough with cast iron rails of much the same pattern as those now used, and put flanged cast iron wheels on the carriages. The normal difference between a tramway and a railway, as then understood, was that on the latter the flange which guided the waggon on the track, was cast upon the tramplate, whilst on the edge railway, as it was then called, the flange was upon the wheel. The advantage that the tramway undoubtedly possessed was that the plain faced wheel could be used off the plates, and might run over planks or hard ground, or into a quarry, where there would be no necessity for laying down a plate. Section-men on the English railways, especially in the old mining districts, are still called "plate layers," a memento of their original employment. In 1805 a great improvement was made when the Walbottle Colliery introduced malleable iron rails, although these were expensive and were only made in two feet lengths. In 1808 Mr. Thompson put down wrought iron rails of an improved section at Tyndale Fell, near Carlisle, and from that date this class of road became common round the Newcastle collieries. The next important improvement was made in 1820, when the Bedlington Iron Works. took up Birkenshaw's patent, and produced a wrought iron rail 15 feet long, with a deepened flange between each sleeper to strengthen the unsupported portion of the rail. These fish-bellied rails were common till long after the Liverpool and Manchester, on which they were exclusively used, was in successful operation, and were the most important improvement yet introduced, linking the old waggon way to the modern railway. The

roads, therefore, upon which Blackett, Blenkinsopp and Stephenson first introduced locomotives were not widely different from those to which we are now accustomed.

The first practical locomotive was undoubtedly Trevithick's, which was placed upon the Merthyr tramway in 1803. There was nothing in this engine to prevent its being as great a success as Blenkinsopp's or Stephenson's a few years later, but it failed from the road being too weak to carry it, and from want of adhesion. The wheels slipped round without propelling the machine, precisely as in the same district two of Sharpe's finest engines afterwards failed, and for the same reason the old shape of the tramplates held the mud and water, and were always excessively dirty. Had Trevithick's engine been tried on a railway instead of a tramway, we should never have heard of that bug-bear, want of adhesion, which frightened all the early engineers. To obviate this supposed difficulty, Mr. Blenkinsopp of the Middleton Colliery, near Leeds, in 1811, took up one side of his railway, and substituted for the rails that had been formerly used others with large cogs cast upon the outward edge. These cogs were six inches from centre to centre, so that there were six of them upon each three feet length of rail. His engines were modelled after Trevithick's, and in August, 1812, commenced regular working. The fact that they did all the work on the railway for five or six years, and long after Stephenson's engines had settled the question of adhesion, is sufficient proof that they were a success. To Stephenson's first engine in 1814, belongs the very great honor of being the machine that set at rest this vexed question of adhesion, or whether the engine could propel itself on the rails and do any appreciable work without some other contrivance than a dependence upon its own weight. There was nothing in the engine itself that was widely different from Trevithick's or Blenkinsopp's engines, yet one had failed and the other had avoided the great difficulty. Stephenson could give no reason for his faith, but he had made some experiments on friction, and with his bosom friend, William Hutchinson, spent a very anxious night in a private trial of the engine before her public exhibition and trial on the following day, July 25th, 1814, when Lord Ravensworth, (who had found the money to build the engine,) the Brandlings and other leading coal owners were invited to be present. This engine settled this one important question, on which more than anything else the modern locomotive rests for its utility. The next year, 1815, and on the same railway the second great discovery was made almost by accident on another of George Stephenson's engines. Hitherto the locomotive engines had exhausted

their waste steam into the open air, and on a neighboring railway, Mr. Blackett's engine had got the name of Puffing Billy, and frightened the horses and cattle for a mile away. In Stephenson's second engine the exhaust pipes were turned into the chimney, and a wonderfully improved effect in its steam-raising properties was at once found. Stephenson constructed a number of locomotives after this at Killingworth, each embodying some improvement over its predecessor, and that these engines were not so very much behind more modern examples is shown by the fact that one of them, built for the Kilmarnock and Troon Railway, in 1817, worked continuously until 1848, when it was broken up.

In 1822, the Hetton Railway, the first for which George Stephenson acted as engineer, was opened with six of his locomotives built at the Killingworth shops. This was a private railway belonging to the Hetton Colliery, but was far in advance of any previous road in its character and details. It had wrought iron rails, and for 20 years afterwards no important change was made either in the road or the locomotives, which all remained very much as Stephenson left them, when he transferred his services as engineer from the Hetton Company to the Stockton and Darlington. This was a public railway constructed under an Act of Parliament, and the first important line that had been so constructed; for although 24 railways had obtained charters before the Stockton and Darlington, and were most of them in operation, none of them were equal in importance or character to the road now under construction by the Quaker coal proprietors of Darlington. On the 27th September, 1825, this railway was opened, was then and has been ever since a model road. It attracted an immense deal of public attention, and produced in fact a sort of a railway mania. Scores of Acts of incorporation were applied for, and of these 21 roads were completed within the next few years. Thus, 1825 is really the date from which British railway construction may be said to commence. Of the roads chartered in that year, the Monkland and Kirkintilloch, opened in 1827, the Canterbury and Whitstable, and the Cromford and High Peak, opened early in 1830, the Leicester and Swannington, on which was a tunnel 1¼ miles long, and the Liverpool and Manchester, opened in September 1830, the Dundee and Newtyle, Bolton and Leigh and the Glasgow and Garnkirk, opened early in 1831, were all roads on which the work was of a superior character and all aided in the development of the modern railway. As each of these roads was designed for locomotives, the question of supplying the necessary machinery

was pressing, and so in 1824 the great locomotive works of Stephenson were commenced, the parties finding the money for the Stockton and Darlington being the original proprietors. Nos. 1, 2 and 3 at the Forth Works, Newcastle, turned out early in 1825, were the same numbers on the Stockton and Darlington, and No. 1, the old "Locomotion," is the engine that now stands on a pedestal in front of the railway station at Darlington. Amongst the first engines built at Newcastle were locomotives for the Wylam, Bedlington and Clarence, private railways, the Stanhope and Tyne, Glasgow and Garnkirk, Dundee and Newtyle, and Canterbury and Whitstable Railways. In 1828 the first engine with inside horizontal cylinders, the "Twin Sisters," was designed at the Newcastle works, and although subsequently built with vertical cylinders, gave the idea of the better arrangement from which she was named. This marked a great improvement in the locomotive, which though departed from in the Rocket, built the next year for the Liverpool and Manchester experiments, was re-adopted on all the other engines for that line, and subsequently became, in the Planet class, the standard Stephenson locomotive. The Rocket was No. 19 at the Stephenson works, and the important improvement that it introduced was the multitubular boiler, the original suggestion for which was made by Mr. Booth, secretary of the Liverpool and Manchester. Though the same idea had previously been patented in France, the Rocket was undoubtedly the first engine built on that principle. This engine, constructed expressly to compete for the premium offered by the Liverpool and Manchester Railway, was finished early in 1829, and on its completion was taken to Killingworth, and there tried on the same railway that had witnessed so many of the early triumphs of the locomotive. But Mr. Clarke is not correct when he speaks of the Rocket as being the type of a class. It was totally unlike, in arrangement and details, any other engine either previously or subsequently built, and the works at Newcastle completely revolutionized all their ideas before the second engine was produced for the Liverpool and Manchester. The faults of the Rocket were apparent from the first day. The glory of being the prize winner in the first locomotive contest was tarnished the next year by its being the engine that killed Huskisson, the member for Liverpool, and one of the warmest supporters of the railway. It was not long employed on the Liverpool and Manchester, being too light for the work, and in 1831, was sold to Mr. Thompson of Kirkhouse near Carlisle, where it once ran at the rate of nearly fifty miles an hour, with the news of the suc-

cessful winner of the Carlisle election. Subsequently bought by the Government for the Kensington Museum; it now commands attention as having largely contributed to the success of the railway system, and the evolution of the locomotive. After the Rainhill competition, the Newcastle shops were busy with the engines for the Liverpool and Manchester, and for the other lines that opened about the same time. The type of engine selected was an inside horizontal cylinder engine, with a heavy outside frame, with outside bearings on the axle, and so pressed were they with the accumulation of work, that only seven of the new engines were placed on the Liverpool and Manchester in time for the opening. Of these the Meteor, Comet, Dart and Arrow had 10-in. × 16-in. cylinders, the last named being the first engine that crossed Chat Moss and made the continuous run from Manchester to Liverpool. The other three engines, the Phœnix, North Star and Northumbrian, with 11-in. × 16-in cylinders, were delivered just before the opening. On that occasion the Northumbrian was driven by George Stephenson himself, and after the accident to Mr. Huskisson, took the dying statesman to his home, 15 miles, in 25 minutes. All these engines were soon found to have grave defects, they were too small for the trains and for speed they were rough and unsteady. A new design was now adopted with larger cylinders and longer bearing upon the road, and the works at Newcastle were pushed night and day to turn out locomotives fast enough. The Planet, Majestic, Mercury, and five others were got out early in the following year, 1831, and ten others, all of the Planet class, were delivered at Liverpool before the end of the year or early in 1832. Other builders were now in the field, and Stephenson built but few engines for the Liverpool and Manchester after this. Amongst others, Bury's works started in Liverpool in 1831, and it was his class of locomotive, and not Stephenson's, from which Norris, Baldwin and others in America principally took their ideas.

As the invention of the truck is claimed almost universally for America, and as it has subsequently become a prominent feature in American locomotives, it may be as well to place on record a few facts, that at least go to prove that the Newcastle shops had something to do with the invention. Horatio Allen was sent to England by the Delaware and Hudson Canal Co., in the fall of 1828, to examine the English railways, and with instructions to order two or three locomotives.

He found Stephenson's works crowded with work and unable to take his order, so that it was finally placed with Forster and Rastrick. The "Stourbridge Lion," the first of the locomotives, was delivered in

May 1829, and was probably the first locomotive ever seen in America. It was intended that this engine should open the railway to the mines on the 4th of July, but the locomotive did not arrive till the 23rd, and was tried on the 1st of August. The engine, which was of the Killingworth type with two flues, was a perfect success, but the road, of hemlock longitudinals 8 in. × 10 in. and a strap rail, spiked down to cross sleepers, 10 feet apart, was too light to carry the weight, and as the expense of altering it was deemed too much, the engine was housed in a shanty for some years. The boiler was afterwards set to work at Carbondale, and the rest of the machinery was never used. The second engine was probably never set to work, at all events, as a locomotive. The first English engine that was actually worked in America was the Robert Fulton, built by Robert Stephenson & Co., and the drawings which accompanied it were dated July 4th, 1831. In the winter of 1832–3 this engine, which was of the Planet class, was altered and fitted with a truck similar to the Experiment engine then on the Hudson and Mohawk Railway, under the direction of J. B. Jervis, and re-christened the John Bull. It is probably this incident, that has led to an error, in attributing to Mr. Jervis the invention of the truck. In looking over the old drawings in Stephenson's office, there is a difficulty in tracing the consecutive numbers, from the fact that in some cases the railway, or party ordering the engine, is put in place of the number on the drawings. Some of the locomotives were thus built to numbers and some to names, but the presumption is that the numbers, where traceable, are consecutive. The Rocket, as before stated, was No. 19 and was built in 1829. The engine for America referred to above has on the drawings "Stevens, New York," built in 1831. In the same year No. 31 for the Stanhope and Tyne, No. 36 for the Leicester and Swannington—the first 6 wheel connected engine—and No. 37, a similar engine sent to the Liverpool and Manchester, are so marked. The next number, still in 1831, is No. 42, ordered by the Saratoga and Schenectady Railway, an engine with 9″ × 14″ cylinders, one pair of 4′. 5″ driving wheels, and a truck with 4 wheels 2′. 8″ diameter. In the same year is an engine but without a number for the Hudson and Mohawk with 10″ × 14″ cylinders, with 4 coupled wheels 4′. 0″ diameter. In 1832, No. 52 is simply marked United States, and was a Planet engine with a single pair of drivers 5′. 0″ diameter. No. 61 and Brother Jonathan in the same year were truck engines built for the Hudson and Mohawk, and so was No. 75 for the Saratoga and Schenectady, all three being 10″ × 16″ engines, with 4 truck wheels 2′. 8″ in diameter. In 1833, three engines were built for the

Newcastle and Frenchtown Railway of the Comet class with 4 coupled wheels. They were named the Delaware, Maryland and Pennsylvania, and have no shop number marked on the drawings. The same year three engines appear to have been built for the Charleston and Columbia, the W. Aitken, the Edgefield and No. 99, and in 1834, three bogy or truck engines Nos. 104, 105, 106, were built for "Pennsylvania," so that from the meagre records left, there are in these four years, the working drawings of sixteen locomotives built by Robert Stephenson & Co., for the United States, of which seven were truck engines. There were other engines built by Stephenson for the States, but the drawing office records do not show their numbers, as the Planet and Comet classes, the first with single drivers and the other coupled, were sent out without comment when similar engines to these were wanted. For instance, two were shipped to the Bangor and Oldtown Railway in Maine about 1836, but there is no number or other record of these than the fact that they were shipped. The Hudson and Mohawk Railway was opened September, 1831, and some time after, but probably before the end of the year, a locomotive called the De Witt Clinton, built at West Point Foundry, was put upon the line, being the second locomotive built in America, the first having been put on the South Carolina Railway in 1830 and having exploded the next year. Both were four wheel engines. In Appleton's Encyclopædia we are told that in August, 1832, an engine called the Experiment was placed on the Hudson and Mohawk with four swivelling wheels, built by Adam Hall of the West Point Foundry. Now putting all these stories together, it seems that in 1831, Stephenson's No. 42, the first locomotive with the four wheel truck was put upon the Schenectady road, and at the same time Stephenson sent an engine of the Planet class to the Hudson and Mohawk, which two years after, was called the John Bull. In 1832, Stephenson sent two engines to the Hudson and Mohawk and another to the Schenectady line all with the truck. In August of that year the West Point Foundry put on their Experiment, probably a copy of the Stephenson engines, and during the following winter, the Stephenson engine, John Bull, was altered so as to be like the three truck engines that they already had.

Besides the sixteen engines built by Stephenson, sent out to the States in these early years of American railroads, Bury sent an engine out in 1831, and others in 1832 and 1833, and the first engines built by Norris, between 1833 and 1837, were in these details almost exact copies of Bury's arrangement. Baldwin's first engine in 1832 was a copy of the first Stephenson engine sent out to the United States,

similar to the Liverpool and Manchester Planet class, although Baldwin subsequently adopted the Bury boiler and inside frame, and Stephenson's truck. From this combination has been developed the present American type, precisely as in England the Stephenson and Bury types, amalgamated and improved, have developed the bulk of the present locomotive forms. Bury from a very early day was Stephenson's principal opponent in the locomotive design, and from 1836 to 1848, it was a moot question which was the better engine. The differences were broadly marked and irreconcilable. Stephenson's standard engine had an outside frame with six wheels, and after 1842, a long boiler and all the wheels under the barrel of the boiler. Bury's engines had only four wheels with an inside frame. Stephenson's fire box was square in plan, Bury's semicircular. Stephenson's frame was of oak, the sides sandwiched between iron plates, and latterly a single iron plate with the horn plates for the axle cut out of the solid. Bury's was a built frame inside the wheels, very similar to the American frame of to-day, which in fact has been evolved and improved from his type. The cylinders of Stephenson's engines were fastened, in fact rivetted, into the smoke-box. Bury's were carried as in the modern engines by the frameplates. The former was a massive heavy-looking design, fit only for a first class railway, fastened and bolted together as if built to last forever. Bury's engines, with their light skeleton frames and all their machinery in sight, looked unsubstantial and temporary beside the other, but proved in practice more accessible for repairs and renewals, and better adapted for rough usage. In 1837, the London and Birmingham Railway was opened with 90 of Bury's engines, and Bury himself became the locomotive superintendent, although Robert Stephenson was the chief engineer of the railway. Of the two types of engines of that day, probably Bury's engine up to 13 inches in diameter was the better machine, but when heavier locomotives were required, the Stephenson type had the advantage. Bury's frame inside the wheels and the cylinders bolted to the frame was, however, undoubtedly the best arrangement, and both in England and America this is now almost universal.

In the Magazine, the author claims for American engineers the invention of two things, which he seems to think the important improvements that have revolutionized the locomotive and made it the success it is. The truck has been already referred to, and that it is an improvement in ordinary work is undoubted. At the same time it must be borne in mind that it has not been universally adopted, and of the locomotives that have recently done such marvellous work between

London and Edinburgh—undoubtedly the best locomotive performance that ever has been done—the truck was not adopted on the engines that did the best running, whilst the locomotive that did the worst happened to be a truck-engine. Comparatively few of the European engines have the American truck, and on some lines, like the North Western, Midland and Great Western, with 6000 locomotives on the three lines, it has not been used. The equalizing lever on long engines of American construction is, no doubt, essential, and either it or the Austrian contrivance of bell crank attachment to the springs with a link between them, (the latter, a lighter and perhaps better arrangement,) is an excellent relief on rough roads. But this contrivance, although perfectly well known in Europe, is not deemed of any great importance where the railways are in good condition, it is by no means essential, nor is it as a rule adopted on some of the leading railways where the best designs are taken regardless of expense. It is absurd to mark these as important developments of the locomotive, comparable to the blast pipe on Stephenson's Killingworth engines, the Booth multitubular boiler, the link motion which regulates at will the expansion of the steam and the power of the engine as it passes over the ever varying gradients of the roadway, or the French invention of the injector which supplies the boiler with water, irrespective of the engine being in motion. If the universal adoption of an improvement is to be the gauge of its value in the evolution of the locomotive, the Glasgow and Garnkirk locomotive, the St. Rollox, which was the first having the gauge glass to shew the height of water in the boiler, or the Leicester and Swannington Comet, where the familiar whistle was first used, ought certainly to be immortalized, and rank far higher than the two inventions specially claimed, and which, outside of America, are only found on a minority of locomotives.

But the author goes further, and claims that in consequence of these two inventions,—the truck and the equalizing lever, American engineers were able to build cheaper and more efficient roads than any previously existing, that they could use sharper curves and steeper gradients than could be worked on British lines, and construct railways economically where the old country engineers could only make them at an enormous expense. Now to refute these statements let us take some facts. One of the numerous railways which obtained its charter in 1825, and was partly opened in 1828, before there was a railway at all in America, was the Cromford and High Peak. It was a line 34 miles

long with rails 63 pounds to the yard on stone sleepers, and all the machinery was the best and most perfect of its kind. It had to cross the Peak of Derbyshire, the back-bone of England, and over some of the roughest country and the finest scenery that even still is the delight of tourists. It connected the Canal system of the East coast from London and Hull with the extension of the Duke of Bridgewater's canal from Manchester and Liverpool, which had been completed to the foot of the High Peak, and it was intended and fitted for a heavy freight traffic, irrespective of passengers. There was necessarily much heavy work, and one tunnel near Buxton, 580 yards long, was unavoidable. Yet it was finished, without machinery, for about £4,000 per mile; and with seventeen incline engines and three locomotives, and all the incline fixtures for less than £6,000. It was Outram's idea that railways would not be able to compete with canals for economical transport, and as much of this as possible was a water level to be some day as he expected transformed into a canal. Of the 34 miles, 29¾ were a dead level. Five inclines, of which four were within the first four miles, carried the road 984 feet vertically in 3306 yards, and four inclines at the West end lowered it again 739 feet in 2112 yards. Two twelve mile levels were to be worked by locomotives. "There are few curves, of less than 1,000 feet radius on European railways, whilst the swivelling truck enabled us (Americans) to build much less expensive lines than those of England, for we could now avoid hills and other obstacles at will. (*See Mag.*)" The curves on the High Peak were all of 132 feet radius, the rails were cast to that curve, and it was an immense saving to have them all uniform, and the rails to the exact radius. The locomotives were not truck engines, they were four wheel engines, and the wheels only 3 feet 6 inches centres, were closer together than the wheels of a truck usually are, and as close, in fact, as they could be placed. Round these curves between 43 and 44 degrees of curvature, these engines, with the device of running on the flanges on the outside guard rail, ran easily enough, and on this beautifully laid road, with its heavy rails and broken stone ballast the locomotives, though small, could handle a very respectable train, as much indeed as could be brought up the inclines at two hauls. Again: "The climbing capabilities of a locomotive upon smooth rails were not known until, in 1852, Mr. Latrobe tried a temporary gradient of 10 per cent. This daring feat has never been equalled." Now this statement is somewhat rash. The question of gradients and adhesion was about as exhaustively gone into on a score of private railways in England, as it could be before the experiments on the Cromford and

High Peak, made in the interest of the Mont Cenis railway, conclusively settled the maximum gradient that it would be safe to use across the Alps previous to the opening of the Mont Cenis tunnel. With ordinary locomotives a 10 per cent. rise is not practicable. On a very fine day, the Cromford and High Peak engines, with a very ingenious sanding arrangement, could go up the Hindlow plane of 1 in 13. On a wet day they could not; but the Fell engines, which were tried on this road preparatory to their being sent to France, could go up any plane, (the steepest, the Upper Goyt, was a little better than 1 in 7,) and take one or two waggons behind them!! The author is not aware, that the Fell engine has ever been tried in America on any of the temporary roads, the switchbacks that Mr. Clarke seems to think are peculiarly an American invention. From the experiments on the Cromford and High Peak they are perfectly reliable up to gradients of 1 in 12, and will take their own weight behind them up such a grade. The locomotive in use on that road weighed a little over 13 long tons, say 30,000 lbs., and it could take easily four cars, each weighing with their load 15,000 lbs. or 60,000 lbs., together double its own weight, up the Whaley plane, averaging 1 in 13, or a rise of 406 feet in the mile. The writer can scarcely have known of these engines, which worked for three years the continental traffic between France and the East of Europe, or he would not have made some of the statements in the Magazine article.

Another great mistake made in connection with English and European practice is the general idea of Americans that everything in the old country is stationary and unchanged, and that the time of evolution and improvement has long since set in Europe to be found now only in America. "The Stephenson type of engine once fixed has remained unchanged in Europe, except in detail, to the present day. European locomotives have increased in weight and power, and in perfection of material and workmanship, but the general features are those of the locomotives built by the great firm of George Stephenson & Son, before 1840." So far from this being the case, the standard engine of the Stephenson works, (Robert Stephenson & Co., not George Stephenson & Son), from 1837 to 1842, has been entirely abandoned since 1844, and although other builders continued that excellent type for a number of years, and perhaps occasionally do so still, the Stephensons entirely gave it up after their patent of 1842 came into use, and this latter style has again since been altogether superseded. The Stephensons, after 1831, never had a monopoly of a locomotive

type. As before mentioned, Bury's engines always formed a separate type, so did the Allan engine, or Crewe engine of 1840, which is still the type of the Northern division of the North Western, of the Caledonian, and of some of the French railways. As far as the locomotive of different countries is concerned, the fixity of type, the absence of change, the slavish following of precedent is to be seen now more in America than any where. You travel from New Orleans to Montreal, from New York to the Pacific, and you see nothing but the one type of locomotive unchanged for forty years, the American 8 wheel, 4 coupled driver, truck engine, with inside frame and outside cylinders, with its Swedish iron laggings, and its monotonous uniformity. In England, on the contrary, the complaint justly made by a recent writer, that the type of locomotives varies on every railway, is unfortunately but too true, and the most casual observer cannot but notice it. The dull red colored machine, with its two coupled driving wheels and single leading wheel, heavy outside frame entirely covering up the inside cylinders and machinery, and which takes you in 4½ hours from Liverpool to London on the Midland, is essentially different in design and arrangement from the bright green outside cylinder engine with its one huge driver, 8 feet 6 inches in diameter, of the Great Northern, or the North Western Compound, with its bright central polished cylinder cover, and its double machinery, each part working its separate uncoupled driving wheel. These three locomotives are as distinctly different from each other as any one of them is from the old Rocket, yet all run between the same termini, and are keenly competing for the same traffic. It is difficult to trace any resemblance between the Mediterranean engine of the great French company, the Lombardo Venetian, or the Belgian, yet all are in a constant state of alteration and struggle for improvement, and each developing and evolving its own type of ideas, and improving its own specific class of machine, although that improvement often, nay always, leads to a further divergence from the common original and from each other. The standard locomotive of the future has yet to be designed.

DISCUSSION.

Mr. F. Brown

It seems very fitting that this excellent paper should have been written in order to refute the misleading statements contained in the Magazine article referred to.

Any writings calculated to disturb existing good feeling and free interchange of ideas between Engineers all over the world are much to be deplored. Different countries have different circumstances to contend with, in designing motive power, and in these designs each contains some good point, which it is to our interest to profit by, and the extent of our mutual profit depends to a great degree upon mutual good feeling, which can hardly be encouraged by the publication of such articles as that which has called forth the paper under discussion.

As to the birth of the Locomotive, the sheets of diagrams with notations showing the growth of the Locomotive Engine, compiled by Mr. Theodore West of Darlington, England, plainly trace the stages of its development. The first we might notice is the Engine of Trevithick & Vivian of 1802, which is now in the South Kensington Museum. This is followed by a long list of locomotives of different types by "Trevithick," "Blenkinsop," "Hedley" and "Stephenson," dating up to 1828, all of which were operated with more or less success *prior to* the locomotive built by Foster, Rastrick & Co., of Stourbridge, shipped *from* England *to* America in 1829. The Engine was named the "Stourbridge Lion," and it was from this locomotive and from others successfully built *in England* and sent *to America*, that the American locomotives have been copied.

With reference to the so called "American improvements," it is certain that our American cousins have proved their well known ability in adopting inventions of others to improve their machinery. But in the many different types of locomotives which have been brought forward in the United States, it cannot be denied that there have been many failures. To-day there is much said about a locomotive which carries nearly as much dead weight as efficient weight; the cost of this machine must be great, but this part is carefully kept in the back ground, and it is evident that first cost is not its strong point.

Again it is stated that "The Stephenson type once fixed has remained unchanged in Europe to the present day." Surely the writer

of this statement must be very ignorant of what is going on in Europe; he cannot have seen Mr. Stirling's magnificent express locomotive with eight foot driving wheels on the Great Northern Railway, which has been in successful operation for over twenty years, nor can he have seen the celebrated four-wheeled coupled express engines on the Midland. Is he ignorant of "Webb's Compound," or that of "Worsdell and Van Borries." And while speaking of Compounds, many will watch with much interest the performance of Webb's Compound on the Pennsylvania Railroad. The speaker would like to see one of "Worsdell and Van Borrie's" Compounds tried in Canada on the Canadian Pacific Railway.

It was said that the first and most far-seeing "invention" was that of the swivel truck, and that this was first suggested by Horatio Allen for the South Carolina Railway, in 1831. The author of such a remark cannot have known of the engine built by Vignoles & Ericsson in 1830, an outline of which is shown on Theodore West's sheet of early locomotives, and we are inclined to ask whether the miserable road-bed in America did not necessitate the use of a truck. If the first English road-beds had been as bad as the first American are admitted to have been, no doubt English engineers would have continued the use of the truck to overcome the difficulty, but it appears they were not called upon to overcome difficulties which did not exist.

Mr. J. Aspinall

The writer has read with great pleasure Mr. T. T. Vernon Smith's most interesting paper upon the "Development of the Locomotive." He has succeeded in getting together in a short space a very large number of facts, which deal with the historical side of the question, and his paper upon that account is a most valuable one. Time, however, does not permit a criticism in detail. He must however be in error in saying "that comparatively few of the European engines have the bogie truck." Again he says that on the Midland Railway, it has never been adopted. This is not quite correct, as there are quite a number of engines running on that line with the bogie truck, and taking the case of the writer's own line,—the Lancashire and Yorkshire Railway,—all the passenger engines built for it are fitted with bogie trucks.

Mr. H Wallis

Mr. H. Wallis said the author had dealt with his subject in an able manner, and the facilities which had been afforded him for research rendered his paper the more valuable, as an historical collection of facts which the Society might be congratulated on having obtained.

There was one name which he thought had been unintentionally omitted. He would be sorry indeed to say aught with the object of detracting from the fame attaching to the name of Stephenson, but the history of the locomotive was incomplete without a reference to the work of William Hedley.

He thought that the credit of having settled the vexed question of adhesion belonged to Hedley, and that the use of the exhaust steam up-turned in the chimney was also with some reason claimed for him.

He agreed with previous speakers that as locomotives had to be designed to meet special conditions in various countries, comparisons without due regard to this fact were apt to be misleading.

Single track railways working heavy traffic required powerful engines, in order to minimise mileage and reduce the delay consequent on the passing and crossing of trains at stations.

Iron and steel for tubes and fireboxes superseded brass and copper with the advent of coal as fuel, the softer metals not having the necessary wearing qualities under conditions of heavy traffic and the forced draught necessitated by the use of the spark-arresting cone in the smoke stack. The extended smoke box was an American device for softening the exhaust and maintaining the draught, which was seriously checked by the interposition of the cone.

The dry atmospheric conditions which prevailed in Canada and the United States required the adoption of means to prevent the escape of cinders and sparks, which were unnecessary in many other countries, but the fact that all such devices more or less interfered with the free working of engines constituted a disadvantage in obtaining economical results.

While American ingenuity had been greatly employed in improving existing inventions, it could not be said to be wanting in originality.

England was undoubtedly the cradle of the locomotive, but the claims of America to recognition for a place in its improvement to meet special conditions could not be overlooked.

The tank engines of the Midland and Metropolitan, or Underground, railways used the bogie truck as a system certainly twenty years ago.

The use of the truck or bogie was to secure an easy motion when an engine took a curve.

The railways of this country were not so expensively constructed as in England, where the receipts per train were higher and the train mileage per mile of railway in some cases four times as much.

The percentage of curve to tangent was naturally therefore in excess,

and, generally, the roadbed was comparatively below the standard of English requirements.

The advantage of the single pair of leading wheels lay in their less weight, larger diameter, and therefore less journal friction at the high speeds for which the passenger service in England was so justly noted.

He believed that bogie trucks recently tried there under fast passenger engines were being replaced by single wheels.

Mr. F. L. Wanklyn said that he had never had the privilege of listening to a better historical paper on the locomotive than that read by Mr. Smith. It certainly proved that English engineers could claim, and very justly, to be the originators as well as the perfectors of the locomotive. Mr. Wanklyn.

What Mr. Brown had said about every country having special requirements and therefore special designs, was very true, and accounted to a great extent for the difference existing between English and American designs. In a good many respects however there was no denying the fact that English engineers were conservative. The fixed grate bar was a case in point. In running sheds in England they would see a number of little boys running round changing the bars. In America, the rocker grate, out of which the bars did not burn so readily, was used. Now English engineers were claiming this as a new invention and putting it into their steamboats. A good deal might be read about the rocking grate in the Glasgow Marine Engineering papers. It was purely an American invention.

Another thing was the persistence with which English engineers would maintain that they could not use the cast-iron balanced valve even in the latest designs of engines with Joy's valve gear, in which the balanced valves could be employed with just as much success as in America. Mr. Webb insisted that the cast iron valve would not prove efficient. They had tried such valves at the Crewe Works, London and North Western Railway, cast of English iron, and had even had some cast of American iron at the Altoona Works of the Pennsylvania R. R., but the results were not satisfactory.

Most of the modern American engines had balanced valves, which eased the strain on the eccentric straps and link-motion, causing the wear to be diminished to a great extent, and also obviating the continual facing and scraping up of valves and valve seats so frequently required in English running sheds. In England they had schemed out screw and steam reversing gears to overcome the friction of the old bronze un-

balanced valve, which hugged the valve seat so tenaciously and made it difficult to notch up or reverse.

Anyone who had anything to do with running engines in England knew the difficulty firemen experienced in tallowing the cylinders. While the train was running at great speed, the fireman had to walk along his engine on a 3 inch angle iron to tallow the cylinders at the smoke box end. In all American engines the tallow cups were inside the cab, and in cases where sight feed lubricators were used, the cylinders were lubricated automatically while the train was being run at its regular speed, or when stopped.

Again, English engineers still maintained that copper was the best material of which to make fireboxes, and that brass tubes were second to none, but they omitted to add that they suffered more from pitted and grooved boilers in their engines than was the case anywhere else in the world. They did not seem to recognize or take into account the galvanic action that was caused by the use of different metals for different parts of the same boiler. In America, in places where the water was equal to the water in England, the pitting of boilers was almost unknown, which was perhaps attributable to the fact that metals of *one* kind were used throughout the boiler. If a boiler was constructed all of steel, corrosive action would not be so likely to follow as with a copper firebox and brass tubes. In England steel had been tried, but, it was stated, without success, due perhaps more to the extra thickness of the plates used than to the quality of the steel itself. It was no use denying the fact that the Americans had adopted a *few* good things in their locomotives which were not English, although the speaker thought there was no doubt that the English locomotive for symmetry and for perfection of design and workmanship could not be surpassed.

Referring to modern improvements in locomotives, he said that he had noticed that quite recently in England they had actually built a tramway compound engine, with an atmospheric surface condenser. He supposed they would soon hear that there was an engine like it in the States, and that the Americans were the inventors, but that invention had been secured to the honor and glory of English engineers, and the speaker trusted it would prove a great success and lead to like engines being used on standard railways.

Replying to Mr. Sproule's question as to the truck, the speaker said that on the Brighton and South Coast Railway, the "B" class express engines had four 6 ft. 6 in. wheels coupled and leading, and they ran from Brighton to London, about 60 miles, in as many minutes. The engines ran without bogie or leading wheel with safety. Again referring

to this question, he said that the object of the Locomotive Superintendent of the Brighton & South Coast (Mr. Stroudley), in using 6 ft. 6 in. wheels, coupled in front of his engines, was simply to utilize the weight of the cylinders and not to have that weight, which is unavoidable in all engines, resting on a truck, without adding to the adhesion of the engine. Mr. Stroudley did not consider it safe to run wheels 3 ft. 6 in. diameter or less, at the speed at which he desired to run his train, and therefore used wheels of 6 ft. 6 in. diar. in front, and 4 ft. 6 in. diar. as trailers. He believed in increasing the diameter of the wheels as much as possible, and not in shoving along an unnecessarily small wheeled bogie truck, the journals of which were liable to heat up and cause trouble on very fast trains.

Mr. F. Brown.

Referring to Mr. Wanklyn's remarks, *re* steel for boilers and fire boxes, the speaker thoroughly concurs with him in all he has said, and may say that the Canadian Pacific Railway Co. goes still further in the use of one class of material for boilers, as they are now using steel, not only for the boilers and fire boxes but for rivets, stay bolts and tubes.

Mr. T. Riches.

The writer, having read with much interest Mr. Vernon Smith's paper, endorses very cordially its general conclusion; but as the locomotive superintendent of a railway—known in England as at least one of the most successful mineral lines, running as it does amongst the Welsh Hills—it may interest his Canadian brethern to learn some few facts in reference to the mode adopted in working some of the many steep inclines—varying from grades of 1 in 12 to 1 in 50, with of course many not so severe.

The incline of 1 in 12 is 1000 yards long, and is worked with tank locomotives having 17½ in. by 26 in. inside cylinders. The fire-box is constructed with a sloping roof, the tube plate being kept up to the full height, but the hinder end lowered 1 in. in 12 in. so that by running the engine fire-box end towards the hill, a uniform depth of water is maintained on the roof of the box.

The dome is also placed immediately over the fire-box so as to maintain dry steam, and the boiler barrel is made conical, enlarging out over the fire-box so as to give freedom to the steam generated, and also so that when the engine comes to the bank head, and gets on the level, the water has a large area to fill, which prevents it becoming inconvenient when flowing back from the cylinder end, which is of course over-full when upon the incline. For work ing down this incline, steam brakes are used, applying cast iron blocks to each of the six wheels (all wheels

coupled), and, in addition, cast iron stays which press direct upon the rails, and are worked by screws and levers.

These engines have regularly worked this incline, which is at a considerable altitude, and subject to very bad weather, throughout the year.

As to switch-back lines, the name is certainly American, but the practice, under the name of zigzag, has been very long used on this side of the Atlantic.

Regarding Bogies on trucks: these are certainly useful in some instances, and for running at high speed upon very sharp curves their benefit will be proved, as the writer has engines weighing 54 tons gross upon ten wheels. The leading 4 wheels are on a bogie truck, having pivot and also lateral slides suspended from compensating radiating sling links, which make it very steady in running. Then come four driving wheels, coupled 7 ft. 9 in. centres, and finally the trailing wheels, carried in a radial axle box. By this arrangement, a wheel base of 26 ft. 6 in. (of which only 7 ft. 9 in. is rigid) works around ten chain curves, many of them an S, with the most perfect steadiness, and at high speeds of from 45 to 55 miles per hour; but for the heavy mineral traffic, and indeed for shunting, after trying a bogie engine against a six wheel engine, all other particulars being identical, the six wheeled coupled engine was proved far more efficient than the former.

The writer can conceive that the very flexible American engine may have advantages upon a very bad road, but for heavy loads upon a reasonably good line, the advantage must rest, both in pulling and cost of maintenance, with the more substantially built engine of English pattern, and although there is considerable divergence even in English practice and design—due in many instances to locomotive superintendents' fancies, but also somewhat to the different features of the railways and traffic to be worked—yet these differences do not amount to much when considering the stable construction of a locomotive engine, as compared with the flexible—but to an Englishman—collective arrangement of pieces composing an American locomotive.

Mr. V. Smith.

Mr. V. Smith said that while with the Stephensons all the documents passed through his hands. It was the intention to destroy them, but luckily they were preserved, and in writing his paper he had looked them up, so that he knew the facts were as stated.

There seemed to be some misunderstanding about the Twin Sisters and about the car from which Mr. Huskisson fell and was killed. He had been told that the latter was not a truck car, but yet the truck

cars referred to were used on the Cromford and High Peak, with which road he was connected for a short time.

He thought that in America engines could not do so well without the truck. He had seen one of Mr. Brown's 19 in. cylinder engines run at 30 miles an hour, where an English engine could not possibly have lived.

It was in the spring of the year near Ottawa, on a road actually creeping, and over which one would not have thought a wheelbarrow could have gone in safety. He would not like to have taken a rigid engine over it. He thought the climatic influences of this country made a truck essential. He had no desire to say anything against American engines. The thin space in the fire-box he thought was an American device, also the use of homogenous metal for the boiler. In England, copper was used in fire-box construction and seemed to answer well, but there might be something in the galvanic action question, and attention should be given to the matter. The balancing of the valves was done 40 years ago, and all the Great Western engines had balanced valves. He thought the balanced valve now used, a great improvement; and for the conditions of climate and the work it had to perform, he did not think there was a better machine than the 8-wheel standard American engine.

Mr. F. Webb.

Reference having been made to the Northern division of the North Western, it might be stated that all the divisions are now amalgamated. The nominal stock consists of only 60 engines with outside cylinders, and 7 ft. 6 in. wheels; all the others, with the exception of 74 compounds, having inside cylinders, while *all* have inside frames.

Up to the present date the compounds have done 10,396,389 miles of the heaviest passenger work. Of the total stock of engines, 1871 have interchangeable eccentric and connecting-rods, and 1665 interchangeable coupling rods.

Mr. Chadwick

Mr. Vernon Smith's paper is a valuable contribution to the literature of the locomotive; valuable not only to engineers, but also to all those who take any interest in the early history of Railways and of the locomotive engine.

The following remarks are made in the hope of eliciting from Mr. Smith, who is so well qualified to give it, some further information about the early days of the locomotive.

Mr. Smith mentions 1847 as the date when cast iron rails were used at Coalbrookdale.

Most writers agree in giving Richard Reynolds the credit of having introduced the cast iron rails there. Reynolds was born in 1735, and

only joined the Coalbrookdale Iron Co. in 1763, on the death of Abraham Darby, whose daughter he had married. During the year 1767 the price of iron fell so low, that the Coalbrookdale Co. had serious thoughts of blowing out their furnaces, when, in order to keep them going, Reynolds suggested the plan of casting flat bars which could be used on the railway in place of the oak rails, and which, in the event of a sudden rise in the price of iron, could be taken up and used as pigs. The idea was carried out, and towards the end of the year (1767), about 6 tons of bars 5 feet long and 4 in. by 1¼ in. thick were cast and laid down.

It may be mentioned here that the early edge rails were cast oval in section with the long diameter vertical, and on each end of the rail was a dove-tail block to fit into a chair. These oval rails, however, were soon found to wear deep grooves in the wheels of the coal waggons, and the form was afterwards altered by making the upper surface of the rails flat. John Birkenshaw's patent for malleable iron rails is dated the 23rd October, 1823, and refers to "wrought and malleable iron rails of peculiar form, instead of cast iron rails as heretofore," from which it would appear that he did not know of the malleable iron rails in use at Walbottle and Tyndale Fell, in 1805 and 1808 respectively, mentioned by Mr. Smith.

In his reference to Blenkinsop's engine, Mr. Smith tells us it was modelled after Trevithick's. It appears, however, that the engine for which Trevithick and Vivian took out a patent in 1802, and which was tried at Merthyr Tydvil, had a single horizontal cylinder working a crank shaft, on which were a fly wheel and two cogged wheels geared into similar cogged wheels on the rear axle of the engine. Blenkinsop's engine of 1811, on the contrary, had two vertical cylinders, from which motion was communicated to the crankshaft below, by means of cross heads and vertical connecting rods. The boiler of this engine was of cast iron, but it proved to be the first commercially successful locomotive, as it was found economical as compared with horse haulage.

Rastrick tells us that about the year 1813 he built an engine fo Trevithick after the patent of 1802, which was exhibited in a field in London, near what is now part of the Euston Road.

Mr. Smith's account of the early locomotives built by Robert Stephenson & Co. is particularly interesting, but when speaking of the Rocket he makes no mention of a second engine of this name, and it may not be out of place to refer to it here, as the two are sometimes confounded. In addition to the Rocket built in 1829, and which was placed in the South Kensington Museum in 1862, an engine of the

same name was built and placed on the Liverpool and Manchester Railway in 1830. There were, however, constant complaints about its being too light and slipping, and Stephenson therefore sent it back to Newcastle, and the following alterations were made:

The 3 feet trailing wheels were removed, and wheels of 5 feet, the same diameter as the leaders, substituted and coupled. In order to get in the larger wheels, the cylinders were altered from an almost horizontal to a diagonal position, as on the Rocket of 1829. A change was made in the position of the safety valve, and the various alterations increased the weight of the engine from 19,824 lbs. to 20,440 lbs. In March, 1832, the engine was bought by the Leicester and Swannington Railway Co., and at the opening of the line in the following July it ran, but the old name plate had been removed, and one bearing the name "Comet" substituted for it. It was sold in 1835, and used as a ballast engine at the making of the London and Birmingham Railway, and in 1849 or 1850 it was disposed of to a South Wales Colliery Company.

Mr. Smith mentions a "Comet" which ran at the opening of the Liverpool and Manchester line, but this engine had 10 in. by 16 in. cylinders, whereas the Comet (formerly the Rocket) had 12 in. by 16 in. cylinders.

As reference is made to the Whitstable and Canterbury line by Mr. Smith, it may be of interest to refer to another of the Stephenson's early engines which ran at the opening of this railway in May, 1830.

The "Invicta" resembled the Rocket in some points, having outside diagonal cylinders, but these were attached to the smoke box end of the boiler, the rear wheels being the drivers. These as well as the leaders were 4 feet diameter and coupled.

In the early days of this railway a considerable portion of the line was worked by stationary engines, but the Invicta hauled the trains into Whitstable and back to the point at which the ropes were attached.

In the *Engineer* of the 10th October, 1876, there is an engraving of the Invicta, and the engine was sent to the Railway Jubilee at Darlington in 1875, and to the Stephenson Centenary in 1881, though in a very dismantled condition.

Mr. H. Wallis.

Referring to the question of priority of claim for the settlement of the vexed question of adhesion, attributed by the author to Stephenson in 1814, he desired to say that Wood, to whose treatise on railways reference had been made, and whose work was published so far back as 1825, and, therefore, ought to be reliable, had stated that Mr.

Blackett in 1813 had an engine made which worked by the "adhesion of the wheels upon the rails." Now Blackett was the owner of Wylam Colliery, and Hedley was his viewer or manager and the designer of that engine. It commenced work May, 1813.

Hedley's experiments on adhesion with smooth wheels and rails were made in October, 1812. He had a carriage constructed, as he wrote to Dr. Lardner in 1836, which was "placed upon the railroad, and loaded "with different parcels of iron, the weights of which had previously "been ascertained; two, four, six, etc., loaded coal wagons were "attached to it, the carriage was moved by the application of men at "the four handles, and in order that the men might not touch the "ground a stage was suspended from the carriage at each handle for "them to stand upon." By this means he says he "ascertained the "proportion between the weight of the experimental carriage and the "coal wagons, at that point when the wheels of the carriage would "surge or turn round without advancing it."

Having discovered the true principle of adhesion, Hedley made his first locomotive, his experimental frame being used to carry it; this engine was tried February, 1813, and failed for want of steam capacity.

Mr. Matthew Dunn (late Government Inspector of Mines in England) in describing Hedley's second engine (the one which commenced to work May, 1813), in his memoir of the coal trade in the North of England, 1844, says:—

"This engine succeeded so well, that it drew eight loaded coal wagons "at the rate of four and five miles per hour and completely superseded "the use of horses."

The "Puffing Billy," to which the author had referred, was Hedley's engine. It was in the South Kensington Museum, having been removed there in 1862, and was said to have been in actual service up to that time.

It was also more than probable that Hedley ante-dated Stephenson in the discovery of the blast pipe. It was probably an accidental discovery, following no doubt upon an attempt to muffle the sound caused by the exhaust steam escaping directly into the air. It was, however, the contracting of the opening of the blast orifice, with the obvious intention of intensifying the draught, which caused complaint to be made by the owners of the land adjacent to the railroad.

Hedley's discovery was made and applied probably two years before Stephenson's engine embodying the improvement was built.

He thought the author would be willing to admit that Hedley's name was deserving of a place in the front rank of those who had

justly earned fame in the inception and development of the locomotive.

The author had stated that the "John Bull" was the first engine which came to Canada, and that it was sent from the United States. The speaker believed, however, that it would be found that the first engine came to Montreal about September, 1835, direct from Stephenson's Works, and that it was named the "Dorchester." There was some difficulty with the fitter who came to erect it, and delay was occasioned by having to send for another man from Newcastle. This engine was still working he believed in a saw mill.

Referring to the remarks of a previous speaker, he was under the impression that the engines which were built at the Canada Works, Birkenhead, England, in 1855, were modeled on the designs of those then in use on the London and North Western Ry. They certainly had outside cylinders, and the bogie trucks were substituted for the single leading wheels at a later date, being sent to Montreal from Portland.

He did not see any necessity for a large increase in the weight of locomotives in future, except possibly for freight traffic, in which case the weight would be spread over an extended wheel base and the number of driving wheels increased.

On single track railways it would be obvious that more economical results would be obtained and better despatch insured by carrying the maximum tonnage per train.

Mr. F. L. Wanklyn referred to Mr. Hedley's method of overcoming the noise caused by the exhaust which seemed to have had the desired effect. In modern tramway engines such as were now being built by Messrs. Henschell, of Cassel, Germany, to get over the difficulty of the noise of the exhaust in the stacks, they still made use of a chamber in which the steam from the cylinder was expanded before passing out in the stack. Mr. Wanklyn.

He desired to record the name of another very able engineer, who, he supposed, had done more towards the development of the locomotive in France and other countries than any other man. He referred to Mr. Crampton, and did not think a historical paper should be printed in the Proceedings of the Society without the introduction of his name. Any one travelling on the French railways to-day would see the Crampton locomotive as designed by him thirty years or more ago. The engine was of a distinctive type. A very large wheel was used behind the footplate, and the weights were distributed in a manner different to that pursued by American and English engineers. Statistics of

continental railways showed that the Crampton locomotive gave better results than probably any other locomotive extant, as regards long mileages between repairs and low cost in fuel, etc.

He referred to different types of locomotives invented and tried in America, and mentioned the "Fountain" locomotive, in which the power was not transmitted directly to the axle carrying the wheels running on the rail, but to a supplementary pair of wheels which only had a frictional contact with the driving wheels of the engine. This engine had actually been tried. Then there was Mr. Strong's engine in which the usual locomotive boiler and fire-box were replaced by a boiler having two corrugated flues, such as existed in an ordinary marine boiler, which led into the combustion chamber and thence into the ordinary tubes of a locomotive boiler.

The Americans also had to be credited with the hard coal burning engine used on the Reading Railway. This engine had the "Wooten" fire-box by which the difficulty of burning hard coal slack was entirely overcome. Four-fifths of the locomotives running on that railway were fitted with the Wooten box.

He also mentioned a locomotive which Mr. Wallis had brought to his notice, and which was purely an American invention. It ran on only one wheel of 8 feet in diameter and about two feet of which were inside the barrel of the boiler. The inventor had been asked whether he had any fear of the boiler spreading on account of the gash in its middle. The first time it was steamed up it opened 3-16 in. The second engine of this kind, now being built, has a boiler somewhat similar to those used in ordinary fire engines, altogether independent of the wheel.

He had mentioned these points to show that there was no lack of originality on the part of Americans, and that they had the courage of their convictions by spending money in building these curious locomotives. He thought it would be interesting to get particulars of the engines mentioned and have them embodied in the proceedings.

In one of the Paris exhibitions there had appeared a locomotive designed and actually built for Russia for traffic on the ice, in which the leading and trailing parts of the locomotive were carried on sleighs instead of bogie trucks, with spikes on the periphery of the driving wheels. He could not say whether it had proved successful or not.

He asked the chairman (Mr. E. P. Hannaford) to give them some statistics showing how the weight of the rails had been increased to meet the increased weight of locomotives. He believed the Permanent Way engineers were alive to the necessity of doing so, and that the weight of rails had largely increased.

Mr. R. Atkinson said that he would have to differ from some of the speakers who had preceded him. He thought that American engineers were more conservative than English engineers. It was hard to get a new feature tried on this side of the Atlantic. Webb's Compound Engine for instance was a long time coming. There were many things about the American engine that might be mentioned in connection with the paper read, which would show that they were largely copies of original English locomotives. To commence with, American engineers claimed the wagon-top boiler with the dome over the fire-box as being essentially American. He noticed that the "Northumbrian" running in 1830 was built in that way, and this was the general pattern of George Stephenson's engines right through. Bury of Liverpool afterwards copied it with a dome shaped firebox and a dome on the top of the fire-box. Mr. Atkinson.

Another feature was the frame, which was neither more nor less than the Bury frame, somewhat modified in detail. If they considered the truck as being essentially American, he noticed that there was a truck engine designed in 1830 by Vignolles & Ericsson, but whether it was built or not he could not say, although the design was made. The truck undoubtedly, as first applied on the Midland Railway of England, gave some trouble. He understood that it was not fixed in any way, and being free to move sideways, there was considerable side motion, so that the truck was afterwards locked and became therefore a rigid centre truck. As now built in Canada and the United States the truck had a certain amount of initial resistance, which on this side was produced by inclined links, which carried the weight of the front end suspended on the truck, and in England by springs put in with a certain amount of initial set on them. He had seen four-wheeled trucks designed for many engines, but all after the Adams principle for English locomotives.

The speaker said the equalizing lever was good with a rough track, and he had seen some extraordinarily bad track passed over in safety.

Referring to details, he said that the only claim the Americans had to the pop valve—originally an English invention—was as to the improvements they had made in it.

In coaches the Americans were now taking the credit of having commenced to build steel frames, while in fact English coaches had for years been built with solid iron frames below and a light wooden superstructure. These instances he said might be multiplied almost indefinitely. On the best railroad in the United States, the Pennsylvania, they were abandoning iron bridges and going back to stone. Of course there were

many good features in American locomotives, as pointed out by Mr. Wanklyn, and the speaker was taking advantage of them as far as he could. At the same time, if the matter were thoroughly enquired into, the efficiency of the American locomotive would be largely diminished if all the English features were removed.

Replying to Professor Bovey's question as to the bogie truck, the speaker said that his experience when travelling over good roads, and on engines with and without the swivelling truck in front, was that he had not noticed much difference in the riding. The Webb compounds he had been on were very shaky, but he did not attribute that to the absence of the truck. In the United States now they had the straight stack and high exhaust pipe in common use. This had been copied from English practice where they had long been in operation. The extension smoke box generally accompanied these engines but not always, and had been tried on this side several times with varying success, though it now seemed to have become the fashion. The necessity for extending the smoke box, it seemed to him, depended greatly upon the fuel used.

Other things, might also be mentioned. There was a tendency in England a few years ago to use a large cylinder, as in the prevailing American practice, and among others the Midland Railway tried it. They had some 6 ft. 6 in. coupled engines running with 18 in. × 26 in. cylinders. These they took out and replaced with 19 in. × 26 in. cylinders, and found they could not run the trains on time. A few years ago also the English engineers got their boiler pressure up to 180 lbs. whereas they had been previously running with 150, and they found it perfectly successful with smaller cylinders for the same work.

When the speaker left England they were running the boiler centres about 7 ft. 6 in. above the rails, which was a high engine. On this side he found the height about 6 ft. 8 in. down to 6 ft. 4 in. if it could be managed. Then followed a high boiler centre, introduced, he believed, by Mr. James Meehan of the Cincinnati Southern R. R., which made a much easier riding engine, and from that time the idea had caught like a contagion, so that boiler centres have gone up as far as 8 ft. 5 in. in a New York, Lake Erie and Western R. R. *Mogul* passenger engine.

A few years ago on this side all the pistons were built up, now it was gradually becoming the custom to use the solid head piston as is the prevailing English practice. He supposed it paid to do so.

With reference to the injector, its invention undoubtedly origi-

nated with the French, but perhaps the most successful injector was the "Automatic re-starting,"—an English invention. It was the best he had ever seen, and gave no trouble whatever.

The Ramsbottom "pick-up" for the water in the tender was now being used on the Pennsylvania R. R. It was successfully and extensively used on the English roads.

Another new feature on this side was the piston valve, which he now saw largely advertised and placed before the public as a late American invention. It was used in Sharpe, Stewart & Co.'s works in Manchester, England, 12 or 15 years ago, and was probably older than that. The motion put into American engines was the Stephenson motion, and many of their own engineers were of the opinion that they could not better it. Their best engines had the Stephenson motion, which gave great satisfaction. The "Strong" motion had recently been introduced to gain power in the latter end of the stroke in the cylinder by the evaporation of the steam; but the power thus gained did not amount to anything, because by the time the expansion had gone through the length of the stroke, if the steam was not allowed to go out, it had to be pushed out by the piston at high speeds. There was no gain in the expansion of the steam beyond a certain point.

The speaker said that the first attempt to build double bogie engines was made by Horatio Allen about 1833. The only Fairlie engines that he had seen working were in North Wales, but he had seen some building in Sharpe's of Manchester. He did not think Americans could claim any priority in the way of signaling. The Saxby & Farmer system was ahead of everything in that line.

A gentleman of his acquaintance having paid a visit to England had remarked on his return that very little was known of railroading in Canada, and that it was his intention to repeat his visit in order to study the question still more.

Two or three attempts had been made to balance the reciprocating parts of locomotives. It was said that an outside cylinder engine was as steady as an inside cylinder engine, but he much doubted it.

If the matter were gone into, he thought it would be found that Americans were trying devices that had been superseded in England long ago. For his part, however, whenever any good ideas were suggested, he gladly availed himself of them, irrespective of their origin.

He thought steel fire-boxes were good and a lasting improvement, where the fuel permitted their use, and also iron tubes, and he supposed that the locomotive was not built simply for the purpose of hauling cars over the country, but to make money. The quantity of

coal burned had to be considered in designing a locomotive. If English coal could be bought here at a paying price, no doubt many locomotive devices would be altered. There would not, for instance, be the same necessity for the extended smoke box and many other contrivances, while the material of the fire-box might also be altered.

Mr. Barnett. So many historical papers are what an editor calls "padding," that our author is to be heartily congratulated on a communication of so wide an interest, and of so much worth.

Mr. Clarke, in claiming for this continent the merit of the adaptation of the truck to railway service, is—as far as locomotive practice is concerned—only repeating the positive claim of John B. Jervis, who says "it is due to myself that the public should understand that I was the inventor," it "is of American origin, and the credit is due to American engineering." (See his "Railway Property," p. 170, first edit.)

Our author's reference to the use of passenger coaches carried wholly on trucks at the opening of the Liverpool and Manchester Ry., settles the matter for that class of rolling stock; but the illustrative reference to double truck timber cars is not quite so satisfactory. As an eye witness, Mr. George Barnett, assures the writer that these were independent cars with a moveable top bolster, secured at the centre by a kingpin, so that the cars and their load of long timber together made an articulated structure, in which the so-called trucks not only revolved on their kingpins, but the long-stuff load could slide and partially adjust itself on the bolsters.

These conditions are, in daily practice, very different from those in which the bolster and long timbers (that is the side frames) are immoveably fixed, and it is evident that the speed of haulage of timber so loaded would be slow.

That Mr. Jervis was familiar with this practice is evident from his letter to the editor of the *American Railroad Journal*, under date of July 18th, 1883, in which he is quite clear on the point that the main frame and its driving wheels are to be (practically) an inflexible unit. This is the essence of his claim—a long fixed or stiff foundation for the engine that shall have at one end a flexible support, this support tending to guide the fixed structure easily around sharp curves.

It is a matter of surprise that Mr. Jervis could see this so distinctly, and yet fail to see how vast the difference between his claimed invention and that of Robert Fairlie, who applied independent power to each of two trucks. In writing to Wm. H. Brown, under date of July 17th, 1870,

he says "all that Fairlie has done is simply to adopt my truck." (See "Brown's History of the first locomotive in America," N.Y. 1874),

If Stephenson's No. 42 was built, shipped, delivered, and working upon the Saratoga and Schenectady road with a truck in 1831, this should settle the matter of priority; but Mr. Jervis dates his letter of claim from Albany, N.Y., in 1833, rather a bold proceeding if he had not good cause to believe that the engines built under his instructions were the first engines in this neighbourhood using a four-wheel-truck. In 1831 he says of his first truck engine—the "Brother Jonathan"—"the plan was prepared in the fall of 1831, and the engine built at West Point and placed on the track of the Mohawk Ry., in the summer of 1832. The boiler proved to be defective, and he designed another truck engine which was built by G. Stephenson, sent out and placed on the Saratoga Ry., in the early summer of 1833" (See "Railway Property," p. 159.)

This is the affirmative American case, and it falls to the ground if there was a truck engine shipped from England in the early part of 1831, that is, previously to Mr. Jervis making his plans for the "Brother Jonathan."

There is another point of view from which the four-wheel truck should be looked at, viz., its effectiveness. Is it under all conditions the lightest, cheapest and most serviceable mechanical device for giving flexibility when the conditions of service require flexibility? This is not proven, and there is evidence to the contrary, as witness the use of single wheel or pony trucks on this continent, and the use of the radial single axle on the European continent. One well known type of radial axle is successfully used by Mr. Webb on the L. & N. W. Ry.

It is only fair to Mr. Jervis to say that he does not claim all the merits for the American locomotive. He candidly states that, "In all that relates to thorough building, and in avoiding tinsel in their engines, the English are our superiors. It would be much better for us, if we substituted wrought iron for much of our cast iron material, and left off the brass ornaments, which are not in sound taste on a machine that is made to perform work, and not for show." And talking of single driving wheels he says: "In this country an engine with one pair of drivers is rarely seen. My opinion is, that one pair of drivers, with three-fourths the weight of two, will do the work of two pair for high speed, with more ease to the engine and less wear on the track." (See Railway Property," pp. 169-171.)

If there is one point in American practice without a single exception to the rule, it is the exclusive use of coupled driving wheels. Unique

as this state of affairs is, the coupling is not an American invention, for the Chevalier de Pambour, in 1836, distinctly credits Mr. J. Melling, Liverpool, with its merit at a date not later than 1834.

No date is assigned by Mr. Clarke to the first adoption of the equilizing beam in America. Mr. George Barnett states that the first he recollects having seen were on two engines supplied by Rothwell of Bolton for the Liverpool & Manchester Ry., 1838-9. As such beams are not readily applied to engines with single drivers, and coupled drivers were only patented in the United States by Campbell of Philadelphia in 1836 (some years after the device had been in use by Melling), it is not probable that equalizer beams had an earlier application in America than 1838.

So rare is the use of equalizer beams on an engine with single drivers, that a current number of the *Railway Gazette*, N. Y. (15th Feb.), devotes an article to its description and recommends its use.

It is a fair inference that they were not used on the earlier single wheel engines, and that their very general use to-day is the necessary result of the conservatism of American locomotive practice.

Mr. C. S. Baker The speaker regretted that he had missed the opportunity of hearing Mr. Smith's paper read and the previous discussion on it.

A good deal of time might profitably be spent in investigating the early history of the locomotive.

A large amount of information had come out by the mention of the names of different men connected with the development of the locomotive.

Years ago Crampton's locomotives, which were specially designed for speed, had attained a name as a standard, and mention might also be made of two other classes of locomotives, viz., those built by Beyer & Peacock of Manchester and Hawthorn of Newcastle.

He remembered seeing a locomotive in the exhibition of 1862 built by the latter firm with a 10 ft. 6 in. driving wheel. The engine had been designed for speed and actually worked a train at about 70 miles an hour. The use of these large wheels had died out because of wear and tear, adhesion, weight, grades and other things, but still the speed had been attained and the locomotives were of a very high class.

He would make a brief referrence to freight cars and trollies. A good deal of lumber was hauled in Canada on flat cars, and in the case of long timber the question of swing centres and trollies had to be considered. If short cars were used swing centres were not necessary, but with cars 30, 35 and 40 feet long he thought they were a necessity. The trouble in carrying this lumber was the sharp curves which

had to be passed round, and it was his opinion that if 40 ft. lumber were carried on two short cars with fixed centres, they would take the curves better than a *long* car with swing centres.

Mr. Sproule said that in reading the articles printed about the claims of American and English locomotives, and other matters, there was so much "bluff" indulged in, that it was difficult for one not an expert in the immediate branch of engineering concerned to know what really were the facts. He would like to ask the mechanical engineers present, whether there were mechanical disadvantages with the bogie truck so serious as to prevent its adoption on English lines. He could see that on a straight line there would be disadvantages with a bogie truck, but where there was any curvature it would be of great value. Was it purely obstinacy on the part of English engineers that they would not use it, or were there really good reasons for their not doing so? For shunting purposes no doubt an engine with a rigid wheel base was preferable and would last longer, but he understood from Mr. Wanklyn that there were lines running trains in England at great speeds with rigid locomotives. He would like to know if these rigid locomotives were better for the purpose than the same locomotives would be with bogies. No doubt the development of railways and particularly that of the locomotive had taked place chiefly in England, where also all the great principles had been first developed. He believed a people became inventive according to their necessities. Mr. Sproule.

The locomotives sent out to the Grand Trunk Railway in 1854, averaged in weight about 56,000 lbs., and were four wheel coupled engines, some of them having inside and others outside connections. They had bogie trucks when received from England. He could not say under what circumstances they came, but they arrived during 1854 to 1860, and whether the Americans invented the bogie truck or not, these engines arrived direct from England with the bogies. Mr. Hannaford

In the early days of the Grand Trunk, English engines with rigid connections were used on construction trains and for ballasting purposes, but the passenger and freight engines generally had the bogie truck. He had also seen engines building in Birkenhead, England, which on their arrival in Canada had the bogie trucks in front.

The heaviest weight per foot of wheel base for a Grand Trunk passenger engine was now four thousand, three or four hundred pounds, and for shunting engines 8,200 lbs. per foot run of 14 ft. wheel base, being six wheels coupled.

He was asked the other day by the Michigan Central Railway Co. whether he could accommodate locomotives weighing 118,000 lbs., six wheels coupled, bogie trucks in front, about 5,244 lbs. to the foot run of wheel base, having 31,300 lbs. on each pair of drivers and 24,000 lbs. on the bogie truck.

In 1884, when the late Mr. Crampton was in Canada he had had the pleasure of a good deal of his company. The question of locomotives came up, and they met at his house an old gentleman, who in his early days had been altogether associated with locomotives in England, and who referred with a great deal of pride to his seven years indenture. Mr. Crampton referred the speaker to that gentleman, with the remark that he would be able to tell him all about 10 ft. driving wheels and why they were given up. Very bluntly the old gentleman told him that 10 ft. wheels were given up because of the difficulty in distributing the weights and of stopping the engine after it had got under way. There was nothing new under the sun, and he supposed large drivers would come into use again at some future date.

He thought the limit to the weight of the locomotive would be reached when the axle would not carry it, and when the friction would be so great that they would have to reduce the weight. The wheels were put as closely together now as they could be, and the axles had apparently reached their limit. No doubt it was economical to have one engine haul as large a load as possible, but there was danger in the great speed reached by heavy engines.

It was true the weights of rails had been increased in England and the United States. They had gone up from 65 to 75 and 90 lbs per yard, but he had found that the rails of 65 lbs. put down 19 years ago would outlast more recent and heavier rails.

There were difficulties all round, and the permanent way engineer and the locomotive engineer were two distinct types of humanity, varying as much as two distinct types of locomotives.

Mr. Atkinson.

In reply to a question, the heaviest passenger engine in general service the speaker knew of was the Michigan Central Railway engine with ten wheels having about 94,000 lbs. on the six drivers. But this was by no means the limit as to weight per wheel. Some 6 or 7 years ago, the generally accepted limit of the weight per wheel of the American engine was 15,000 lbs., but, after severely condemning English practice, some of their designers had gone up to 19,500. One of these engines was on the New York, Lake Erie and Western Railway, of which Mr. J. W. Cloud was the Master

Mechanic. As well as he could remember, the wheel base was 8 ft. 6 in., which would give 78,000 lbs. on the fixed wheel base.

The London, Tilbury and South End Ry. engine was built at Sharpe, Stewart & Co.'s works, Manchester, England, and weighed according to the weights given there 56 tons in working order. He remembered the engine well, as he had worked upon it.

He thought credit was not given to the right person for the large grate for burning anthracite coal. He believed the Americans claimed it for James Mullholland of the Philadelphia and Reading R. R. He had heard the Wooten engines were being taken off the Reading roads.

He understood that the bottom of the boiler was pocketed when the driving wheel went up to 9 ft. 6 in. in the English locomotive. It should not be forgotten that there had been a great leaning towards small driving wheels in American Locomotives, but it was now being recognized that it did not pay to run a 5 ft. driving wheel on engines working fast passenger trains, and in consequence wheels had reached 6 ft. and 6 ft. 3 in diameter. The English practice might eventually be followed in that particular also.

Mr. Vernon Smith.

The author feels very gratified at the interesting discussion which has been elicited. There are doubtless many shortcomings and some mistakes in the paper, which was intended not so much as a history of locomotive improvements, as a defence of what he considers the claims of his countrymen for certain developments now generally accepted as important factors in the modern engine. There are many ingenious appliances desirable in locomotive practice for which American engineers deserve all the credit, but it certainly appears that the earlier steps in railway development, especially the items claimed in Scribner's Magazine, are not of the number. For the correction of errors pointed out by Mr. Aspinall, Mr. Wallis, Mr. Chadwick, and others, the author is thankful, while for the solid information from Mr. Riches, Mr. Atkinson, and most of the speakers, the Society as well as the author is under obligations.

With respect to the use of the bogy frame or truck upon the Midland Railway in England the following explanation must be made. The Midland was formed by the amalgamation, May 10th, 1844, of the former North Midland, Midland Counties, Derby and Birmingham and Sheffield and Rotherham Railways, to which shortly afterwards the Birmingham and Gloucester and other lines were added, and from these different lines about 200 locomotives of every form, shape and variety, were put into the common stock. Among the others, the Birmingham and

Gloucester contributed about 50 engines, of which some 20 were bogy engines. This line opened in part for traffic June 24th, 1840, at which time there were 12 engines on the line, 8 of which had been imported from Norris & Co., of Philadelphia, the "England," "Philadelphia," "Columbia," "Atlantic," etc. With the exception of one, which was larger, they all had $10\frac{1}{2}'' \times 18''$ cylinders, with 4′ 0 driving wheels, and four 2′ 6″ truck wheels. The other four on the line were six wheel outside cylinder English engines with an outside sandwich frame built by Forrester of Liverpool. The engineer of this railway, Captain Moorsom, who was connected with the Norris family by marriage and spent much of his time in America, loudly extolled the working of his American engines, on which, at that time, there was an import duty of 20 per cent. Subsequently other "bogy" engines, built in England by Lancashire builders, on the plan of the American engines, were added as well as others of a different type, so that by 1846, when these came into the hands of the Midland, there were about 50 engines on their books. No engines worked more inefficiently or disappeared more quickly. Of the few bogy engines left in 1849, after an average life of 7 years, about four were altered into four wheel tank engines for shunting, and in 1851 not one of the original Gloucester engines could be traced in the then Midland stock, excepting 8 which were put on in 1845 and 1846, and which were not bogy engines. After 1846 until the Midland reached London and ordered from Beyer Peacock the Underground engines, the author believes he is correct in saying that there were no bogy engines in use on the Midland, and with the exception of the Underground engines and a few express engines, he does not think there are very many now.

With reference to Mr. Chadwick's interesting remarks about the early engines of the Liverpool and Manchester and Leicester and Swannington railways, he is in error about there having been two Rockets. The old celebrated Rocket was the only one of the name. Having cylinders of only 8-in. × 18-in. it was too small for the Liverpool and Manchester, and was sold to Mr. Thompson of Kirkhouse. Previously to going on to his railway, it was very much altered at Newcastle, the cylinders being placed more horizontally as the motion of the spring had a serious effect upon the slide valves and altered the distribution of the steam. The engine ran for Mr. Thompson for a number of years, and before being sent to Kensington Museum the angle of the cylinders was again altered to make it as nearly like the original Rocket as possible.

In 1832, Stephenson built the Comet and the Phoenix for the Lei-

cester and Swannington, having 12 in. × 16 in. cylinders with 4 ft. 6 in. coupled wheels. Both these engines were subsequently sold, the Comet first to Mr. Smart, a contractor, and then to the author for the Babbington Colliery railway, where it ran till it was broken up. This was a very complicated engine, and does not appear to have ever been altered. The cylinders were very low, the piston rods working at an angle underneath the leading axle. There were only 13 bearings to oil on the crank shaft, for there were two outside bearings in the main frame, three inside bearings, one in the centre, and one inside each wheel with a spring on the axle. There were the two main connecting rods on the inside cranks and two coupling rods on the outside cranks, and besides these there were two dummy connecting rods fixed one on each side of each cylinder, with brasses in the big end, keyed up to the axle on each side of each crank. The engine was worked by two loose eccentrics which were driven for the forward and backward working each by two dogs, one on each side of the eccentric, which engaged the eccentric by moving longitudinally on the axle, the projecting dog passing into a square hole in the eccentric sheave after the engine was in motion. To start the engine there was a lever attached to each slide valve by which they were worked by hand, and then a third lever slipped in the proper dog to drive the eccentrics when the projection of the dog was opposite to the hole into which it fitted. As this hole could not be seen amongst the mass of moving and stationary connecting rods it sometimes was a difficult thing to get the engine to work. A man seemed to want a third hand, as all three levers required moving to start the engine.

In reference to early locomotive building there is no firm that deserves more honourable mention than the Hawthorns of Newcastle. Their shop, situated next to that of Stephenson, with only a brick wall between, is nearly as old. If Stephenson built Nos. 1, 2 and 3 on the old Stockton and Darlington, the numbers immediately following from 6 upwards were the Hawthorns engines, and of the earlier engines of that line the Coronation, Wilberforce, Swift and Sunbeam were amongst the most successful. The Hawthorns also built the Hurricane in 1837 with 10 foot driving wheels to carry out Brunel's idea of immense speed, and when no larger wheels could be designed, they built the Thunderer with 6 foot coupled wheels geared 3 to 1 so as to be equivalent to an 18 foot wheel. The Thunderer, like the Hurricane, was short of power. The latter could take two of the smaller Great Western carriages. The Thunderer objected to more than one, and did better without any.

To the Hawthorns' inventions many of the recent locomotive designs

may be traced, as, e.g., the Fontaine engine, which is is clearly the outcome of the Thunderer. They also introduced the perforated steam pipe taking steam all along the boiler and saving the dome. They used return tubes through the steam space to superheat the steam, the chimney being at the back of the engine over the firebox, and they gave the first idea of the Joy gear by dispensing with eccentrics and driving the valve motion from a pin in the connecting rod. They greatly simplified many of the details of the locomotive, and were the first to use four eccentrics and only one lever to do all the reversing. Another great name that ought to be mentioned is that of Bury, nor should his partner Kennedy be forgotten.

It must always be remembered that as 1825 is the date when railways assumed their present shape and modern rudiments, so 1830 is the year from which the modern locomotive really dates, and that not the Rocket but the Planet is the type and base of the present engine. It is difficult now to decide to whom the leading features of the Planet are due. The enormous working expenses of the early engines, including the Rocket, and the Liverpool and Manchester engines like her, left but little improvement, excepting as to speed, in the locomotive over horse traction, and no advantage whatever over rope traction. Hackworth's "Globe" engine, Stephenson's Planet and Bury's Liverpool all made their in appearance in 1830, and were the three first horizontal cylinder engines that were built. They all embodied the ideas of the present locomotives, and Bury's engine was closely copied both by Norris and Baldwin, the first practical American builders. Hackworth's "Globe" saved the locomotive from being "bounced" from the Stockton and Darlington, as up to her time, horses were the cheaper and more reliable power, but the Planet enabled builders to turn over a new leaf and produce an engine that was something better than an expensive toy.

Thursday, 28th February.

E. P. HANNAFORD, Vice-President, in the Chair.

The discussion of MR. T. T. VERNON SMITH'S paper on the Development of the Locomotive occupied the whole evening.

Thursday, 14th March.

E. P. HANNAFORD, Vice-President, in the Chair.

The following Candidates having been balloted for were declared duly elected as

MEMBER.

STANISLAS REMI POULIN.

ASSOCIATE MEMBER.

THOMAS DRUMMOND.

ASSOCIATES.

GEORGE BROKITT ABREY. WILFRID THIBAUDEAU.

STUDENTS.

LOUIS BENJAMIN COPELAND,
GEORGE MITCHELL,
PETER J. MURPHY,
N. B. MCTAGGART,
FOREST RUTHERFORD,
AVILA THOMAS,
WILLIAM S. TOWNSEND,
WILLIAM HENRY WARREN.

Paper No. 29.

WORK SHOPS,

THEIR DESIGN AND CONSTRUCTION.

By J. DAVIS BARNETT, M. CAN. SOC. C. E.

The author wishes to record a few notes on the design and construction of railway shops, and purposes not only to treat of the peculiarities that mark those of North America, but also to contrast some features with European practice, and if possible to indicate what is and what may be the modern development and progress in this art.

LOCATION.

A natural starting point is the *location* of the shops with reference to the terminal stations of the railway, and to some large town ; also the choice of land and its amount. A statement of the best American practice in this matter is given by Mr. C. Paine in the chapter on "Shops and Engine Houses" in his "Elements of Railroading." A point he strongly emphasizes, that *more* than enough land should at first be purchased (even if afterwards it is sold as building lots), will receive a unanimous endorsement.

FOUNDATIONS.

It would, for the present purpose, be a waste of time to enumerate those matters common to all dry, solid and effective foundations, but it may be remarked that in Northern climates, it is better that the sides of foundation walls and piers be *sloped* rather than stepped, so as to prevent as much as possible the earth gripping the wall, as it expands under the action of frost.

When the main supports of the overhead weights—such as roof-principals, crane-tracks, shafting, etc., are iron pillars; and "made ground" covers to any depth the natural foundation bed, the comparatively low price of iron has proved it to be economical to build short foundation piers, and to allow the iron pillars to run down below floor level, to the piers, instead of carrying up the piers to floor level, the pillars being socketed into broad cast-iron bases, bedded in cement.

Pillar footings and column bases, when above floor level, are usually bedded on rolled sheet or melted pig lead. The author is of the opinion that the running in, between base and cope stone, of a fine cement grout, would be quite as neat and effective, and certainly cheaper. Less concentrated weights, such as stationary engine and pump beds, and the footings of heavy machine tools, are satisfactorily bedded on their foundations with melted stick-sulphur.

Another instance of iron being used, to reduce the first cost of foundation, may be seen in the new erecting shop of the Grand Trunk Ry. at Stratford, where, instead of making continuous walls to carry the rails supporting the traverser table, it was found less costly and quite as efficient to build disconnected piers, and span them with wrought iron beams of I section, which carry the rails laid upon them longitudinally, and support the flooring laid transversely.

WALLS.

It is advisable to emphasize the apparent wall construction; a good shop *looks* substantial. This is best accomplished by using bold pilasters or large piers to receive all roof and floor beams, setting them so that they stand out prominently, and spanning the panel between them with comparatively thin bonded walls, free from bats, if of brick.

This method of straight lines and prominent offsets not only satisfies the eye, but is of pronounced value in localizing and absorbing the vibrations received from the roof or machinery, and closer attention to these matters would result in our shops having a less tame—a less ugly—appearance, and a longer safe life. The permitted outlay on such new works rarely admits of the wall surface being broken into ornamental

lines, or varied in color; but it is always possible to make a strong bony skeleton, whose very angularity will instinctively satisfy, by appearing to be quite equal to its special duty.

ENGINE HOUSES OR LOCOMOTIVE SHEDS.

Intended for little else than the temporary storage of locomotives, engine houses in America vary more in first cost and permanence of material used, than in type of design. The ordinary arrangement in plan is an annulus or segment of an annulus—whose centre is that of the unroofed turntable, giving access to the radial tracks each leading into a single locomotive stall. The economics in the construction of the annulus are: either a narrow span of trussed ridge roof; or a so called flat roof (angle 5°), offering little obstruction to wind, and permitting the use of an inexpensive roof covering: low walls—the roof timbers are sometimes lower than the top of the engine chimney—and a short length of wall, as it is limited to the ends and outer ring, the inner ring being formed by the wooden door and door posts. A flat roof supported by pillars gives a very stiff building for the limited amount of material used, and if sloped inwards, the roof drainage is a simple matter.

The stack of the locomotive naturally going to the higher part of the building brings its front end close to the outer wall containing the windows, so that the most light is received where it is needed—on the moving parts of the machine.

Extending back into sparsely settled districts, as do many of the new railways on this continent, the primary consideration, in the erection of their buildings is low first cost, a future development of traffic, being relied upon to provide the revenue for erecting permanent structures. Hence, segmental engine houses of wood, with flat gravel-covered roofs are common, and if the materials for the ashpit, and its drainage, do not prove unusually expensive, they can be built for $850 per stall, the foundation consisting of cedar posts, 6 or 8 feet apart, carrying a mud sill, on which rests a pine frame of 6 to 8 ins. square scantlings, the roof being single sheeted with 1 or 1¼ in. tongued boards, and coated with paper felt, tar and gravel; the ashpit, 25 ft. long, being of brick or stone, and one iron smoke-jack being provided. The shell of a similarly roofed building with brick walls and stone foundation costs about $1000 per stall.

It was common some years ago in northern climates to sheet with inch boards on both sides of the scantling, and to fill in between with sawdust. This hastened decay by holding water and vermin, and the better practice now prevails of putting both sheetings outside, with tarred felt or thick paper between them. The use of clapboards or

shingles for outside sheeting, much improves the otherwise primitive appearance of such an engine house.

The more permanent structures of this class are of brick, and those of modern date have roof principals, rafters and deck ridge beams of wrought iron throughout; the covering being of slate, preferably of small size, 8 by 16 or 9 by 18, with a quick angle or slope, at least equal to $\frac{1}{4}$ of span, which is never less than 66 ft.

In Canada, slate is rarely used for shop roof-coverings. Mr. J. W. Harkom (Member) informs the Author, that he has used New-Rockland slate on an engine-house in Maine for five winters without repair being needed, and he is familiar with roofs that have been covered with it for ten years, that show no injury from frost. Our native slates are very compact,—a point greatly in their favor. A report of the State Geologist for Vermont shows that the slate in this neighborhood has a water absorption (under vacuum test) of but $\frac{1}{400}$ of its weight. Mr. Harkom also mentions a successful experiment he carried out at Arthabaska, with the object of getting rid of the icicles that form at eaves, due to melting from heat communicated through the roof slating. He double-boarded or sheeted on the purlins, and then laid wood strips $1\frac{1}{2}$ by 1 inch thick on top, at proper distances apart, to which strips the slates were nailed. The air space below secures fairly equal temperature on both sides of the slate, thus preventing the excessive eave icicles common to slate covered engine-houses.

The fire risk from a roof covering of shingles—set in cement and occasionally lime-washed,—is very slight; in fact in high winds, with many live sparks flying about, it is probable that shingles so treated are safer than slate.

A liberal surface of glass is provided in the outer ring wall. Skylights flush with roof, being difficult to keep clean both inside and out, are of little use; and the small portion of each large door (forming the inner ring) that can be fitted with windows, makes it necessary to depend largely on the outer ring wall for natural light.

As to the number of engine stalls required, any railway in a moderate climate, having an engine house capacity equal to 60 per cent. of its locomotive stock, is well equipped; many American railways being content with 50 per cent.

In Great Britain a very common form of engine-house is the *longitudinal*, with parallel through tracks, and exit at both ends. Their capacity varies, rarely exceeding 80 engines. The roof is usually of the saw tooth pattern, a series of narrow spans, supported by hollow iron pillars, forming conduits for the water from gutter in roof valley to

under ground drains. The roof is hipped unequally, favorite angles being 60° and 30°, and that side more nearly vertical is glazed with $\frac{3}{8}$ inch rolled or rough plate, and if possible is arranged to face North, so as to give a good light equally diffused throughout the wide building, without too much inconvenience from the direct rays of the sun. Snow and frost prevent the saw tooth roof being used in Canada, (the Author not knowing of a single example on this continent north of the State of New Jersey,) hence our roofs are of single slope ("flat") or single ridge of quick pitch, and as skylights have but a partial efficiency, the necessity for securing light from the side walls limits the width of a longitudinal engine-house.

An excellent example of this type of house built by The Grand Trunk Ry. at Montreal, is 76 ft. wide by 282 ft. long, with five parallel tracks through it, giving liberal accommodation for 25 long tender-engines. Any increase in capacity, could only be obtained by lengthening the building and tracks, which increases, out of all ratio, the difficulty of working the longitudinal type of house. This difficulty is the trouble and extra movement of other engines necessary to get a locomotive out and ready for service, should one on the same track in front of it, be undergoing for a few hours such light repairs, as the renewal of truck wheels, that prevented it from being moved until the work is completed. American criticism says that this is the main defect in the longitudinal type of house. It does not, however, in daily practice prove to be as awkward as it looks, if definite tracks are reserved for such repairs and for such engines as have to keep "shed-day" while their boilers are being washed out, and if the house-men (engine turners) learn what part of the house each engine should go to, before attempting to put it under cover.

Exit at both ends of such house, cannot be obtained where the yard room is limited. At Cardiff, on the Taff Vale Ry., England, the Locomotive Superintendent, being compelled to have one end of his new engine house blank, put in the middle of its length a traverse pit and table, crossing its ten tracks and then passing out, through a pocket on side wall, to a parallel siding in the yard. This gives practically three exits, with exceptional economy in space. (See Proceedings Inst. C. E., Aug., 1884, p. 243.)

The Great Western Ry. of England has in many of its engine houses, combined both the longitudinal and the radial systems under one continuous hip and valley roof, and the North Eastern Ry., England, had such a preference for the radial system, that five turntables were put under one roof, 280 ft. wide by 450 ft. long, giving stallage for 95

engines. This is an extreme case and is probably unique, although in passing, it may be noted, that the late Howard Fry, in designing the extensive workships for the West Shore Railway at Frankfort, N. Y., laid them out so that the smithy, boiler-shop, foundry, erecting and machine shop stand radially to an open turntable. Having, however, unlimited land at his disposal, the tracks from the outer ends of these buildings are connected by easy curves to the yard sidings, so that a failure of the turn-table or the blocking of its pit will not necessarily lock up all entrance to these shops, such being the case with the tracks in an engine house, which converge on a central turntable as their sole means of exit. The Burlington and Missouri River Ry. at Plattsmouth, Neb., also has most of its shops in the shape of segments of an annulus centering on one turntable.

The best radius of track curve is an unknown quantity, but the New York Central Ry. safely uses curves as quick as 160 feet radius for their city freight-house.

The author would strongly endorse the longitudinal type of engine house. It is eminently serviceable where a large number of engines have to be turned out almost together in the busy portions of the day. An English officer, daily handling about 400 train engines at one terminal, in comparing the two systems, said, that if turntables controlled the exit of his engine houses, he believed it would be impossible for him to get the engines out on time for their trains, even with additional space and men placed at his disposal.

And this type as readily suits small establishments. An engine-house recently erected by the Grand Trunk Ry. at Lindsay (under the supervision of the Author) is 250 by 62 ft. It has two through tracks, with continuous ash-pits for 10 running engines, one through track for engines under repair, being washed out, or waiting under steam between trains. Parallel with the windows of one side wall, are two stationary boilers with overhead apparatus for sand storage and drying, three smiths and other fires, a stationary engine, a force pump with underground water supply tank, and still continuing in line with the shop and main shafting, are wheel lathes and other iron working machinery, the fitters' benches, and the wood working tools and benches, followed by foreman's office, clerks' office, and a two storied storeroom, with oil tanks below ground, the whole resulting in a cheap compact arrangement, every foot of floor space being used, while every corner and detail is well under the eye of the foreman. The tracks in yard form a triangle (or Y, as it is called) and a turntable with its pit is dispensed with, thus getting rid of one, source of probable failure and delay in getting engines out "on time."

Many engine houses are now equipped with a continuous pipe 1½ or 2 inches diameter, having branches to each stall and flexible couplings to each engine. Its uses are various. The steam and water from a boiler to be "blown off" and washed out, are sometimes used to heat the water with which the washing out is to be done. The pipe may be passed into a boiler of cold water, so as to shorten the time in raising steam after a washed out boiler is refilled, and sometimes, it is connected with the jet-blower at base of locomotive chimney, and the steam used in creating a draft to quicken up the newly lit fire. The two latter arrangements prevail where an injector or inspirator is used to give the washout water-pressure.

OIL HOUSE.

A special feature of American engine-houses,—the outcome of the extensive use of mineral oil for lubrication as well as for light—is a detached oil house; a fire-proof brick structure with iron roof, roof covering and shutters, and concrete or asphalt floor. Underneath it (below track level) are iron storage reservoirs, with inlet pipes so arranged that oil received in bulk can gravitate from the tank-car into any one of them, from whence it is lifted by hand or steam pump into small tanks on upper floor, and is drawn thence by tap for engine and train use.

The concrete floor is at level of car-floor, or about 4 ft. 2 in. above rail level, to facilitate small shipments to out-stations, which in the more perfect equipments is by means of circular iron tanks holding 60 gallons. The cellarage around storage tank and the house, is warmed by steam pipe from outside, and the artificial light is gas, or as at Indianapolis, electric, no lamp or torch being admitted.

SAND HOUSE.

The sand used to increase the adhesion of locomotive wheels would at first sight seem to be too small an item to require specific attention; but eight or ten tons is a daily issue at central stations. At Columbus, O., the sand store, having a capacity of 1,000 tons, is a neat wooden building with hinged shutters at top of walls, set so as to permit the air to assist in sand-drying; and the floor is of dry brick set on edge, with tile-drain below. When required for use, the top layer of sand is shovelled into hoppers, containing live steam pipes one inch diameter and spaced two and a half inches apart; when dry it falls through bottom opening on to a concrete floor.

The Grand Trunk Ry. has recently, by hand power, belt and bucket

elevators, lifted the dry sand into overhead reservoirs, from whence it is allowed, through hose and molasses gate, to deliver directly into sand-box on top of locomotive boiler.

COAL SHUTES, ETC.

Equipment for coal delivery to Tender may be passed over (the author having treated on this matter at large elsewhere), also the details of water supply and delivery, as the varying local necessities do not permit any uniformity in this matter.

GENERAL REPAIRING OR ERECTING SHOP.

The amount of floor space to be devoted to the general repairs of locomotives and tenders, and its proportional division among the various buildings, is a wide question, on which little has been written; and in attempting to find an average taken from existing practice, difficulty is experienced, due to so many workshops manufacturing supplies for out-stations and for other departments, even when not manufacturing new engines.

Simply for repair purposes, the Author is of opinion that there should be floor or stall room in the erecting (repair) shop for 10 or 11 per cent. of the total engine stock. It may be expected that 4 or 5 per cent. will be in the paint shop going out, or in yard waiting to come into erecting shop for general repairs, and that 5 per cent. are having their boilers washed out, or undergoing running repairs of so trivial a nature, that they can be done in the engine house. This leaves 80 per cent. of the motive power effective and at work daily.

To illustrate—we will suppose the total number of engines on a railway to be 100; the working engines make a daily average of 133 miles or 4,000 per month, which multiplied by the 80 effective engines gives 3,840,000 miles per annum, and the repairs done in the erecting shop have to balance the wear and tear of this mileage.

The first question is one of time: How long does it take to repair an engine? An average common in America is—

Heavy repairs occupy 90 days—equivalent to a wear of 100,000 miles.
Medium " " 60 " " " 70,000 "
Light and specific repairs occupy 30 days—equivalent to a wear of 30,000 miles.

General average is 60 days (2 months) to a wear of 67,000 miles.

Each engine on a general average, occupying a stall for two months, gives the output of repaired engines for an erecting shop containing ten stalls as 60, which multiplied by the average mileage of 67,000 totals to 4,020,000, a sum just in excess of the mileage during the same period by the 80 effective engines.

There is (or should be) some relationship in size, between the erecting and other shops of the locomotive department, and Appendix A. gives from recent practice the comparative area of the other shops in percentages of the erecting shop.

It will be seen that the proportions vary; and it must be so when some establishments build more or less new work, while others are restricted to repairs only; some are confined to locomotive work, whereas in others material is manufactured for all departments, including even the telegraph department.

Also the "size" relationship will be varied by the uniformity and interchangeability of the parts of the engine stock. Where their classes and styles are few, all the shops will be comparatively small, and the delay to engines in the erecting shop less. Thus any such table will only permit of a mean average being taken.

This being the case, under each heading is a second column, in which the size of each shop is given as a percentage of the whole—so that, given the total roofed surface that can be devoted to the locomotive department, its proportionate divisions can be approximately inferred

In America, the ordinary arrangement for erecting shops is, that the pits or stalls lie transversely to the main axis of the building, admission to them being by a transfer table or traverser, within the building in northern latitudes, and outside it where snow is likely to cause but little inconvenience. There is an obvious economy in size and cost of structure when the traverser can be put outside; but its free movement cannot be insured during a Canadian winter, and an attempt to use one in Montreal was, after much inconvenience, abandoned years ago. Hence, the shop must be wide enough for its work, and for the length of the traverser in addition, at once giving a span of roof justifying the use of intermediate supports. Two rows of pillars are often used, dividing the floor space into three bays, one on each side of and parallel with the traverser pit, as this brings the work and men close to the side windows. When the traverser is outside it is rarely that the floor is obstructed with more than one line of pillars. Whatever be the number and disposition of these internal supports, the roof is invariably of the single ridge, or gable pattern.

TRAVERSERS OR TRANSFER TABLES.

It was due to traversers being framed in timber that the pits in which they moved were at first so deep—even exceeding five feet. Rolled steel is now used for the frame, which is suspended from the

axle journals on both sides of eight small wheels, and for which four parallel rails are provided, the full length of pit. Much ingenuity has been used in the endeavor to reduce the inconvenience of the pit, by making it as shallow as possible, and at Reading, the Philadelphia and Reading Railway in its new car shops has no pit, only a flush asphalt floor from wall to wall. As, however, the suspended or carrying rails of the traverser must be higher than the fixed rail over which they move, it is arranged that the tracks at each repair stall, instead of being spiked to cross-ties, are carried upon longitudinal timbers about 10″ square, thus lifting them above the floor level, and giving the necessary difference in height between the traverser bed-rail and its suspended rail. The author is not familiar with any example on this Continent, of the European practice of making bed-rails for traverser and the transverse or stall tracks, flush with each other and continuous, except where slightly cut at intersection to allow the wheel flanges to pass. The shallow rails on the traverser only just clear the bed track on the floor, and the vehicle to be transferred mounts to them by running up tapered extensions of the suspended rail that are hinged—or rather pivoted—on its ends, and which when not pressed down by the wheels of the on-coming vehicle, are kept clear of the bed tracks by springs. This practice may be said to be a development of the "Dunn Traverser," at one time in common use for the transfer of carriages at terminal stations on English and Continental railways.

Having all rails flush, not only permits the rapid movement of men and small material, but allows the transfer, when traverser is engaged, of vehicles from a stall on one side of bay to the track immediately opposite. Having in view the possible failure of the traverser, some shops are, and all should be, provided with portable rails to span the width of pit.

Power to move the traverser is often communicated direct from boiler and engine carried upon it. This, though convenient enough, perhaps, for out-door service, has proved to be an unmitigated nuisance under cover in winter, when doors and windows must be kept closed. Endless chains, the full length of the bed with stopping and starting gear at one end, are sometimes used. The friction is considerable the chain having to be supported every eight or ten feet, and signals to control traverser movement have to be transmitted over long distances.

Stout wire cable, travelling at same speed as chain, offers less resistance, and if one of the forms of clip gear is used on the traverser, the single attendant travelling with it has its motion completely under con-

trol. The cable grip clip gear, used at West Albany, New York Central Ry., is a simple form of friction brake stopping the revolution of a set of three geared wheels. When locked, the traverser moves at same speed as rope. Two sets of such wheels are used, so as to give both up and down motion. When table is at rest, power is transferred to a capstan used in hauling vehicles on and off the traverser. At Alton, Mr. W. Wilson causes a small quick moving rope to give motion to one wheel and shaft, from which power to traverser and capstan is communicated through bevel friction wheels. Speed of traverser is slow, 25 ft. per minute, and that of the capstan is but 32 ft. per minute.

The outdoor traverser, built some years ago for the Wason Car Shops, Springfield, is 50 ft. long, and weighs 11 tons, being propelled by a boiler and engine of 12 N. H. P. A steam pressure of 15 lbs. will move it without load; 30 lbs. with heaviest passenger coach on, and 60 lbs. gives it a speed of 500 ft. per minute.

An interesting and successful attempt has just been made at Aurora, on the Chicago, Burlington & Quincy Ry., to give motion to a traverser and capstan through an overhead electric wire with a small trolley running on it connected to a 7½ H. P. Sprague motor. Its rapid motion is geared down, so that table can be run either at 100 or 200 ft. per minute. The table is 65 ft. 9 in. long by 15 ft. wide, and weighs empty about 15 (short) tons. The tractive resistance, unloaded, is about 250 lbs., equal to 17 lbs. per ton; loaded, it is 1500 lbs. or 37 lbs. per ton. Experiments on the Coln Minden Ry. at Deutzerfeld give the resistance of a traverser and load weighing 20 tons at 440 lbs., equal to a tractive resistance of 22 lbs. per (long) ton.

Cotton ropes moving at 3360 ft. per minute, are used (under cover) at Cologne on the Rhenish Ry., for coach traverser, friction clutches being used to change the speed, so that the table has a motion of 197 ft. and capstan of 64 ft. per minute.

Erecting shops equipped with traversers at low level, need in addition some means of lifting an engine off its wheels, and a hoist is usually fixed in the roof timbers either close to entrance or in centre of length of shop over the traverser bed. Lifting power is variously communicated to hoist by belt from shop shafting, by hydraulic pipe, by pneumatic pipe, and even by hand labour.

OVERHEAD TRAVELLING CRANES.

The European practice of making the erecting shop narrow compared with its length, using three (or at most four) longitudinal tracks

and spanning them for their whole length with overhead power traveling cranes, has not often been adopted in America, although we have specimens at the Canadian Pacific Ry., Montreal, at Altoona, West Burlington, Indianapolis, Roanoke, and at Hamilton, Ont.

Why so effective a method has been comparatively neglected, it is not easy to say, as by its use there is an economy in floor space, and the cranes can do duty for both traverser and hoist. Undoubtedly the roof, or a portion of it, must be carried up higher, so as to give head room for the cranes and their load to pass over engines being repaired; but the interest on this outlay and on that of the cranes (often exceeding the cost of both traveller and hoist), is but a fraction of the money and time saved in the daily working of the shop.

Two fish-bellied plate girders, extending from sidewall to sidewall, with their ends supported on plate box trollies, usually form the crane bed and carry one—or better still, two—travelling crabs. An independent boiler on crane—as a source of power—is now rarely used; but from the shop shafting motion is communicated to the crane by quick moving rope of steel wire, hemp, cotton or rawhide. If the distance crane has to travel is short,—say under 150 ft.—or if it is used in the foundry where heat and dust would materially shorten the life of a fibre rope, then longitudinal shafting (grooved or square), supported on tumbling bracket journals, is often used. In almost all cases where the winch forms part of the trolley, the transfer of motion to it from the end of crane is by such a shaft, although in the original cranes of this class designed by Mr. Ramsbottom the high-speeded cord was carried along the crane girder through the trolley to opposite end, and then back to side wall, bending the cord often and shortening its life.

Messrs. Fowler of Leeds use steel wire rope similar to that used in steam ploughing: their 12 ton crane being equipped with a $\frac{5}{8}$ in. diameter rope, moving at 270 ft. per minute. One, of 40 tons capacity and 50 ft. span, has the rope speeded to 400 ft. per minute, giving a slow lift of 2 ft. and a fast one of 4 ft. per minute, with a cross traverse of 28 ft., and a longitudinal motion of crane and load of 30 ft. per minute.

A 20 ton crane, using manilla rope of full $\frac{3}{4}$ in. diameter, running at a speed of 2540 ft. per minute, has a slow lift of 3 ft., and a quick one of 51 ft. per minute, with a cross traverse of trolley carriage of 16.8 ft., and a motion of the whole crane of 47.5 ft. per minute. It has the hoisting winch at one end, thus permitting the use of a 45 ft. span single box-girder partially open below, the trolley carriage travelling inside the box on the angle-irons forming the lower web.

The seven original Ramsbottom cranes at Crewe used long fibre cotton

rope ⅝ in. diam., weighing 1½ oz. to the foot, having a tension of from 17 to 18 lbs. and a speed of 5000 ft. per minute. Larger diameters, lower speeds, and cheaper material, are now used, as at Swindon, where 4½ in. rope at 970 ft. per minute is employed. Messrs. Penn have used raw-hide rope moving at 1,500 ft. per minute: and a 50 ton crane employed on dock work has had five years service, without showing any wear on raw hide rope of 1½ in. diameter.

At Aurora and Altoona, cotton rope with speeds of 5,000 ft. per minute are used, giving with the 25 ton cranes of the latter, a slow lift of 15 ft. and a quick lift of 81 ft. per minute, a crab traverse of 30 ft. and a crane travel of 50 ft. per minute.

The two cranes at Alton have each two crabs, so that the engine is suspended and independently moved at the four corners, a decided convenience when dropping frame and boiler on the wheels.

Where possible it is an advantage to put the crane attendant's platform below the main girder and close to the wall, so that the work below and not the crane machinery is in his view.

Pneumatic floor cranes for light weights, although not common, are used at Wilmington on the Philadelphia, Wilmington and Baltimore Ry. and at the Paige Works, Cleveland. The Missouri Pacific Ry. uses compressed air at from 60 to 80 lbs. pressure, to work small three-cylinder Brotherhood engines for giving motion to boring, valve facing and other portable machines, the air being compressed by a Westinghouse brake pump and distributed through small pipes. In the engine house, or in the shop after ordinary working hours, such portable motors can be coupled by rubber hose either to the air pump or the boiler of the nearest locomotive in steam.

The pneumatic transmission of energy is not in itself economical; but for the small powers mentioned it is far cheaper than shafting and more rapid than using manual labor.

At Seraing all classes of shop cranes are pneumatic. The reason for this practice is that with the large area under continuous roof the volume of pure cool air exhausted is of value in assisting ventilation and increasing the general health of the workmen.

Our shops, sheds and freight houses are rarely designed with the object of reducing manual labour in lifting, and many of us feel the regret expressed by Mr. Don J. Whittemore, ex-President American Society of Civil Engineers: "I could not prevail on our people to make use of cranes to the same extent that they are used in England, and in this we are at fault." As an after-thought, pillar and other fixed

cranes are occasionally applied, but their value and efficiency is limited, and for equal outlays, by far the most economical results follow the use of movable cranes. Hoisting by unskilled labour is one of the most expensive parts of the old fashioned plant which American shops yet retain. Recent experience in the use of hydraulic drop-pits for removing single pairs of wheels, (although with all its advantages an inelastic convenience) provokes such strong commendations and approval as a labour and time-saving machine, that it is probable that the period is not far off when overhead power-lifts will be common in our shop equipment. The wear on the metal work of cranes is not rapid, and an allowance of five per cent. per annum on first cost, covers all depreciation, except in the matter of lifting chains which require care and frequent testing. Wire rope has replaced lifting chains with economical results, its only defect being an increased diameter in pullies and drums, the increase (about 25 per cent.) not being excessive as the speeds are slow.

To support an overhead travelling crane track, the plan usually adopted is, to increase the thickness of the brick side wall pilasters, and arch over the window and door openings flush with pilasters up to the elevated track level, thus securing a solid, safe support for crane travel, with the disadvantage of materially reducing the width inside shop and the window openings. Rolled iron, bolted to the walls, both for pillars and girders would to-day be the better practice. A good arrangement is to use stout cast iron pillars to support both the crane track and the roof principals, filling in between them with walls of just sufficient thickness to keep out the weather. It is difficult to use a single section of wrought iron for this double purpose, as the support for the track must be bolted on its side, and the weight from the crane is not then brought directly over the foundation, resulting in a tendency to throw the heel of the pillar outwards, and put the roof principal into compression. By using cast iron pillars, and varying their shape at the upper end, there is no difficulty in bringing the crane weights vertically on the underground foundations. The Author is not familiar with any example of a cast iron pillar doing such double duty in any northern climate.

TRANSMISSION OF POWER.

In power transmission throughout workshops, small shafts, light pullies and high speed flat leather belts are common in, and belong properly to, America; but there is a growing tendency to dispense with shafting in favor of rope, and to use hemp or manilla rather than wire rope.

Examples of the use of wire rope are to be seen at Altoona, St. Paul, Proctor, and the Buffalo, New York & Philadelphia Ry. has run its machine shop 312 ft. distant, with ½ wire moving at a speed of 6,900 ft. per minute, for two years without repair. At Columbus, motion is transmitted by hemp rope moving at 1,500 ft. per minute, and Mr. Drummond at Cowlairs, Scotland, uses rope throughout, even for transmission at right angles,—circumstances under which the Grand Trunk Railway prefers the use of V leather belting. Satisfactory instances of the use of hemp rope between engine and main shaft may be seen in Montreal at the Grand Trunk Railway shops and at the Redpath Sugar Refinery. A rope 2 in. diam., moving at 3,000 ft. per minute will transmit 25 H. P.:—that is, a duty equivalent to a 4 in. belt moving at the same speed. Three-ply manilla rope is better than four-ply. The pullies should be at least 30 times the diameter of the rope, and the shafts not less than 20 ft. apart, the angle of the groove in pulley rim 40°, the rope not being allowed to bottom in groove as in the case of wire rope. Some actual tensions are as follows: a manilla rope 6½ in. in circumference, with a speed of 2,972 ft., transmits 23 H. P. with a tension of 256 lbs., another at 3,782 ft. transmits 40 H. P. with a tension of 349 lbs., a third has seven ropes of 1½ in. diam. at 2,355 ft. transmits 34 H. P., with tension of 476 lbs., the tendency with increasing experience being to increase the tensions, which are still far below those used with iron and steel wire ropes. Hemp apparently suffers little from climatic influences and its life especially at the weak point—the splice—may be lengthened by coating it with beeswax and a little plumbago.

The Southern Railway of France has probably made the most complete application of hemp rope in the minute division and transfer of power. The through shaft in the shop is provided with numerous V pullies by which motion is given to three-quarter inch diameter hemp rope, so that at every point the power may be delivered to light overhead cranes as well as to numerous specially designed portable machine tools. For instance, in the boiler repair shop, not only are the drills so worked at any angle or in any corner, but the holes are tapped, and the screwed stays put in, much in the same way as similar work is done to a limited extent with the Stow flexible shaft.

Electric transmission has been used in Germany for some years under restricted conditions. It has some advantages, as the conductor is less clumsy than shafting, steampipe or rope, its position can easily be

changed, and the motor is compact and less of a nuisance than a small steam engine. Loss of power there certainly is, but not much in the actual transmission between points far apart, if wire of reasonable diameter is used, and the less the power being taken off, the less is the percentage of loss in the transmitter, the opposite rule holding good with shafting. The chief loss is in the use of double machinery, the first to convert motion into current, and the second to convert current into motion. Every month is simplifying the problem and minimizing the waste; and the ready adaptability of electro-magnetic machine tools (without intermediate machinery) to the varied purpose of drilling, tapping, rivetting, chipping and caulking thick steel ship plates in position, their high duty and rapidity of work, are shown in the paper by Mr. F. J. Rowan, recently discussed by the Institution of Mechanical Engineers (see Proceedings, Aug., 1887), in concluding which he expresses his belief "that it will be found both economical and otherwise convenient to adopt electrical distribution in engineering workshops, instead of the existing system of shafting and belts, or even hydraulic distribution of power."

Transmission of power by steam pipe and independent engine for each shop has, up to date, not been common in countries liable to low temperature. In mild climates, the use of separate wall engines with the cranks coupled direct to shop shafting is most satisfactory, and a pair of locomotive cylinders are often use for such service, as the engines occupy little if any floor space when set vertically, and each shop can be run independently when it is necessary to work overtime.

With the use of modern asbestos and silicate coverings, there is but little loss by condensation in the long steam pipe. Mr. W. T. Bird in his careful experiments (see North of England Institution of Mining Engineers. Proceedings 1882–3) has shown that the condensation in an exposed pipe 1,000 ft. long is sufficient to reduce the steam to 76 per cent. of its boiler efficiency, while coating the same pipe with silicate cotton raises the efficiency to 95 per cent.

MACHINE GROUPING.

At one time the aim in arranging a machine shop was to group the large machines close together, so that the heavy and bulky material steadily progressed from one to the other without retracing its path. With the adoption of light overhead cranes and single rail tramways for moving heavy weights, the rehandling of raw material has lost much of its importance and most of its expense, so that the favorite arrangement is to mass similar machines of all sizes close together, permitting

one skilled man to be put in charge of the whole class. An alternative —when a charge-man is not employed—is to put one skilled attendant to each pair of such machines. However, the main advantage is that the whole floor space can be more fully utilized when machines of a class are massed, than when different machines of about equal size and capacity are grouped together.

When small machinery is placed on a narrow side gallery, it is better, if window light will permit it, to locate a double row of machines, back to back, in the centre of the gallery, thus leaving a narrow passage on each side, rather than to put them in two lines with the passage between them. This grouping enables each attendant more easily to keep his raw and finished material separate from that of his neighbours, and there is less countershafting needed. Its one defect is that it brings the attendants—usually boys—close together and face to face. Mr. W. Wilson has this arrangement of lathes on the ground floor at Alton.

The solidity of machinery designed for railway shop service permits tools with single cutters to take wide and deep cuts, and in milling machines allows of a much higher speed at cutting surface (by virtue of which they are rapidly displacing shapers, planers and slotters). The actual depth of cut has little influence on the cutting speed; hence, it has been found at the forge not economical to smith too close to size. This refers, of course, only to hand work. All wrought iron stamped or worked out under "formers" should, for several reasons, be made close to size.

FOUNDRY.

Foundries for the production of iron castings rarely form part of American railway equipment, yet no shop returns a larger interest on the capital invested, is more useful in the rapid despatch of daily work, or more helpful in case of emergency. That these benefits may be realized, its design and details should not be fortuitous, even if many of them now in daily service suggest the inference that, like Topsey, they "growed."

Many years service—as well as recently created shops—shows that a most convenient plan is to divide the surface to be roofed over, into two sections of about equal length and span, placing them at right angles to each other, with the cupolas in the inner corner as the most central position without occupying floor room, the square of open land behind the cupolas being utilized for storage of scrap iron, fuel, &c. The

foundry at Point St. Charles is practically based on such a ground plan, although an existing building was utilized for the purpose. (See Paper by Mr. F. L. Wanklyn (Member) in Proceedings Inst. C. E., vol. 88, part 2.)

Overhead travelling cranes are preferable, so that the molten metal will not need transfer from one crane to another; but if jib-cranes must be used, one set in front of and between the two cupolas will swing into both sections through an arc of fully 270°. The sand stores, core ovens, &c., being set close to inner wall, light is received through windows in the long outer walls.

What may be considered a model foundry has recently been completed at the Pittsburgh Locomotive Works. Mr. D. A. Wightman, the Superintendent says: "One of its peculiarities is the location of the core oven and core room, which are placed below the level of foundry floor, the top of the core ovens being on a line with said floor, and the runways—used by trucks out of the ovens—are covered, all except a hatchway left open for dropping the heavy dry sand cores and mould, down with a crane.

"The core room is on the same level with the core oven floors; but is left open at the top of the foundry roof, and receives its light from the main windows of the building. Communication between the core room and the south side of the core ovens is had by means of a passage way under railway track. The sand pits all open out of the core rooms and have manholes outside for shoveling the sand through from wagons and cars.

"This arrangment of core ovens was suggested in trying to obtain suitable light, as on one side at least nearly all foundries have their light shut out by core rooms, core ovens, and cupola house. The plan adopted obviates this difficulty, and you will probably conclude after examining the drawings that this building has better light from the ground than any foundry you have ever seen.

"The sand conveyer indicated on plan is simply a Gandy Belt, placed beneath the surface of the foundry floor, upon which the sand is thrown, from any point where it may be lying, and conveyed to an elevator which delivers it into a revolving screen, thence falling into the hoppers over the moulding machines, which are kept fairly full, so that upon opening them at bottom, the flasks are filled very quickly. The conveyer saves the labour of wheeling the sand up to and shoveling it into the moulding machines. One man takes care of all the sand for the two machines, whose output in castings varies from 5,000 to 12,000 lbs. per day."

BRASS FOUNDRY.

An effective, well ventilated and therefore healthy brass foundry is a square, single-storied, semi-detached building, with the windows, moulder troughs, and core benches on the three open sides. A circular chimney is in the centre, having around it a ring of crucible furnaces below ground level. This arrangement requires separate core ovens on the face of blank wall, an expense justified where the output is large. In smaller foundries, the furnaces are in line in front of a blank wall, the flues between furnace and chimney passing around the core ovens, the chimney being supported on iron girders, six or seven feet above floor level, so that any portion of the furnaces, ovens or flues may be renewed without disturbing or weakening the chimney.

SMITH'S SHOP.

The smithy used to be a narrow shop, with the fires ranged close to the side walls and an open central passage. This arrangement has been modified, as the large machinery which is displacing hand work is most conveniently set in line down the centre, with a passage on each side of it—that is a track between the machinery and each line of fires; hence smithies have increased in width from 40 to more than 60 ft. Certainly the smith does not need much window light, yet he should not be made to stand between his work and the window when at the anvil, as is done when the fires are set at right angles to the sidewalls. The better plan, which has long prevailed at Sir W. Armstrong's works and elsewhere, is to group them in pairs set parallel to the wall.

A recent experimental attempt to draw off the forge smoke through underground flues by the natural draft of a 140 ft. brick chimney was not successful (whatever may be the result with higher and costlier chimneys). The most complete method of doing this, as at the Valley Falls shops on the Pittsburg and Western Ry., is to connect the smoke stack of each fire with a central smoke flue running parallel to and under the ridge of the roof, providing it at the outlet with a suction fan blowing into a short chimney, whose draft it improves. Brick hoods and smokestacks make a permanent arrangement when each fire or group of fires has a separate outlet; but if the building is to be kept fairly clear of smoke, movable sheet plate hoods are needed.

For ventilation, small flues from outside, passing through dwarf brick pilasters about two feet above floor level, with horizontal gratings opposite and under the control of each man, are effective for the admission of air, the smoke stacks or movable louvre boards in clerestory on roof being depended upon for exit, though neither are satisfactory at low temperatures unless the smoke flues have induced draft.

Pressure blast for fires should be distributed in overhead galvanized pipes, with a branch down to each set of hearths, and provided with hinged collapsing valves that freely fall open inwards when there is no pressure in the pipe. This simple device prevents any inflammable gas from accumulating in the mains after the fan is stopped, thus avoiding explosions when lighting up.

The number and variety of steam hammers is increasing, and as the interest on the first cost and the foundation for the handier sizes, does not amount to the wages of a striker, and as there is no comparison between the relative usefulness and productive value of the two, each new smithy is likely to have a larger number. The points in the setting of steam hammers worthy of note, are:—that the foundation for standard and for anvil must be kept quite distinct, that solidly bolted timber on end, makes one of the best supports for the anvil block, and that as no foundation fully absorbs the throb of a large hammer, the forge and smithy should be removed as far as possible from the shops holding tools of precision, but not beyond reach by a standard gauge track siding, with some yard-room being reserved near at hand in which to store the scrap, fuel and the steel dies, or "formers" that accumulate around a well used hammer.

BOILER SHOP.

The boiler shop in all satisfactory works is detached, so that the noise of hand rivetting (not yet completely dispensed with) may be as little of a nuisance as possible. In height and width it is often a duplicate of the erecting shop, but with flush floor. It is worthy of note, that some works on this continent not using overhead travelling cranes in the erecting shop, appreciate their usefulness so far as to equip the boiler shop with them.

The hydraulic and other heavy machinery for handling thick plates is massed at one end, and the lighter equipment for thin plates and tender tanks at the other end of one side of the shop, the floor on the other side being left open for actual construction or repair. The plate furnace (with forced draft) is set, so that its flue may have a short run to the chimney erected for the forge or smithy, and close to the heavy flanging tools.

Standard gauge as well as trolly tracks cover the floor and the plate store (or rack) is close to main the track and to the furnace.

Accommodation should be ample, for the boiler shop, as most managers find, is one of the least flexible; and therefore it is wise to give it space and a full equipment of modern tools.

FLOORS.

European practice in flooring, varies from wood block on solid foundation to plain block and plank, using clinker, hard packed cinder or clay in the smithy, and concrete or asphalt for paint shop. The German Railway Union recommend stone or tile—except where men stand at machines, and here wood should be used. Slate gives—all things considered—the best service and wear under foot, of any known substance, and being light, strong and durable can be strongly recommended for stairs and steps. The continuous concrete floor used at Columbus, has for its first course, six inches of broken stone, for its second, eight inches of finely broken stone mixed with cement, and for the finishing course, a compound of Portland cement, asphalt, and sand, four inches deep, which being slightly elastic, is not readily cracked by a sudden blow.

South and West of Pennsylvania a solid floor is made by rolling the earth, and then bedding, about thirty inches apart, half-round locust stringers in four inches of concrete, before it sets hard. The stringers are floored with two inch Georgia pine plank coated with hot tar. Oak flooring is often used in that neighbourhood, not because it lasts any longer than white pine, but because it is cheaper in the local market. The Georgia Central Ry. coats the sills with rosin, packs the earth up to within half an inch of their top, spiking the planking down after boring holes through it. Rosin is then run in through these holes until the whole cavity is full, thus completely isolating the timber from the damp earth. In Canada a cheap floor for light weights is made by bedding half-round cedar in a foot of engine cinders, and nailing two inch pine plank on top.

Sellers, of Philadelphia, uses under his machine tools a continuous iron floor resting on brick foundation walls, and between the machines pine plank for the workmen to stand upon.

TURNTABLES.

The American pattern of turntable is a "top deck" structure of cast iron up to the common diam. of 60 ft. The weight of table and load is carried on a single fixed central pyramid, with one of the many forms of antifriction caps on the top, to lessen the resistance to movement. No gearing is used to give the table motion, a short lever or hand spike stands out from one end, and two men are usually sufficient to walk the table and its load around.

A fixed circular rail in the pit and end wheel trollies at the outer ends of the girders are provided; but they come into use and carry weight only when the load is being moved on or off; at other times the

table is in balance, and the trolly wheels ride just clear of the ring-rail.

When the turntable girders are of cast iron, it is advisable to dispense with any lock or catch to hold the table in line with the radiating tracks, on account of the danger to the castings, if the bolt is shot out suddenly while the table is in motion and because the engine-men will move an engine on to the table more carefully, when it is held in position by hand, than when it is locked.

With wrought iron tables these precautions are not so necessary, as they are not liable to failure by sudden side jar, but almost all wrought iron tables designed or built by dealers to their own specifications ultimately prove to be lacking in stiffness. For locomotive service, wrought iron turntables of 75 ft. diam. have been used at Roanoke, Virginia, with the object of getting rid of the frogs in the radiating tracks (which tracks were of mixed gauge).

Turntables of 100 ft. diam. are invariably of wrought iron with deep side girders, the load being carried on the bottom deck, and the weight supported and moved upon small tapered rollers massed in a ring of 10 or 12 ft. diam., the whole being similar in design to the ordinary form of "draw span" in American swing bridges, and therefore not lacking in stiffness. Part of the weight must be carried on the outer ring-rail, so as to restrict within narrow bounds, any tendency to balancing on the central ring support.

The motive power is usually an independent boiler and engine, running on the ring rail, and coupled to one end of the table by drag-links or other special form of adjusting connection, so that the oscillations of the table under unequal loading shall not interfere with the adhesion of the engine on its single rail.

In running sand about three years ago, the author put in a central foundation for a 50 ft. table, by making a timber hollow box frame of pyramid shape, 10 ft. square at base, 5 ft. square at top, and 4 ft. 6 in. deep, weighting it with rails to sink it as hand labour excavated the material from the centre. When the top was sunk flush with the level of pit, the anchor bolts, passing through two 12 in. baulks, were put in place, and the whole filled in with quick setting concrete. A sand pump was kept going the whole time until the frame was filled, and the mass was finished flush, to receive the base of the centre casting, no cap-stone being used.

CAR SHOPS.

The roofed space provided for the repairs of freight cars is usually limited, as twenty-five per cent. of this work can be done in the open

air. The time occupied in the heaviest repair—viz., a rebuild—is short, and the detention of a car in the shop is brief, compared to the delay in the case of a locomotive, so that a total shop surface that will shelter one and a half per cent. of the freight car stock, will be found sufficient. It is probable, if the figures could be obtained, that an average for this continent would show but one per cent., and the nearer the approach to uniformity in detail in the car stock, the less the shop room needed.

The total outdoor track space provided for repairs, change of wheels and shop storage, is twice that under cover. There are in this matter wide variations in practice, due to climate and nature of traffic, the cars moving food, clothing, &c., requiring different treatment from cars moving coal and heavy minerals.

Table No. 2, Appendix B, gives from recent practice, the relative area of some American car shops, the percentages being shewn in double columns (as explained for Appendix A).

The annular form of car shop with radial tracks is occasionally used in America, requiring a turntable of exceptional dimensions—usually 100 ft. in diameter—to permit not only a coach or two freight cars, but also the small tank locomotive doing the shunting, to turn upon it. A large amount of shunting is required in and about a freight car repair shop, due to the short time occupied in an average repair to a car, and the passage of each vehicle over a turntable adds both to the time and to the cost of shunting.

The supposed difficulty in utilizing the whole floor space of a longitudinal shop, and which the annular shop was designed to avoid, is the delay in taking out a string of cars until all are finished, thus sometimes keeping the workmen idle waiting for work. However, even in one of the best examples of the annular shop, that of the Pennsylvania Ry. at Altoona, the radial tracks were intended to be three cars long, and therefore some sorting and dividing of cars is necessary before they can be put in, and all that the other type, with its long tracks, requires, is that this classing together of cars be done with a little more care and judgment, so that the whole string will be finished and ready to shunt out at the same time. There are good points in favour of the annular shop, if it is intended exclusively for new construction, one being the ease and rapidity with which material on trollies is delivered close to the workmen.

However, the author would endorse the longitudinal freight car shop which is of the simplest construction, often wide enough for six or seven parallel tracks, and from 200 to 500 ft. long. The walls, of brick or wood, the roof almost flat (the slope each way from middle

being about one in twelve) and supported by timber posts eight or nine inches square. The posts though numerous do not seriously interfere with the work. The roof covering is cut for numerous skylights, gable-shaped and of quick pitch. Usually the floor is flush, that is, neither track pits, cranes, nor hoists are provided. The car bodies to be lifted, being light and bulky, and requiring in many cases to be sustained after they are lifted, it is found best to use quick moving hand jacks to lift, and dogs or trestles to effectively support them while the men do the work of repairing.

Numerous trolly roads cross the building in both directions, their union at intersection being made by cast iron turnables revolving on a central spindle. These tables may be of two castings, a base, forming both pit and foundation, and a revolving top with socket on underside.

This building and its contents are so liable to destruction by fire, as to justify large water pipes and numerous fire hose hydrants within it, as well as without.

There is no real economy in the endeavor to repair freight cars and passenger coaches under one roof. The work is so different in character that men can rarely be transferred from one class to the other, and the dirt and dust inseparable from the cars should be kept away from the coaches. When both classes of repairs are done in the same building, it is imperative that a shop free from dust and at a higher temperature be used for painting and varnishing coaches in. It is often built directly opposite to the car repair shop, with a transfer table between. Here, as elsewhere, entrance from both ends of a longitudinal shop is desirable, and has been obtained in many recent designs.

At the Como workshops on the Union Pacific Railway, each stall in the paint shop is provided with an electric call bell, communicating through signal code, both with the foreman's office and the paint store, which latter building, as in all railway shops, is detached, and as far as possible of fire proof construction. Often it is provided with an underground cellar for the storage of all inflammable fluid. According to the best practice only one man at a time is allowed to work in this house mixing the paints and blending the colors, and in some cases the brushes and other tools used by the workmen are stored here and only issued as required. It is a "paint tool-room" in which much the same system prevails as in the "machine tool-room."

WARMING AND VENTILATION.

Paint shops need special facilities for warming and ventilation. A successful arrangement is the use of a fan to draw air through a nest

of small steam pipes, and then to force the warmed air into a light galvanized iron tube, from which it is passed into overhead branch pipes and delivered through slide-gratings below, the slides being within the control of the workmen.

At Columbus the paint shop is 75 by 135 ft. containing 272,665 cub. ft., and the steam pipes have a surface of 1,034 ft., or one superficial ft. per two hundred and sixty-three cub. ft. The fan has a maximum delivery of 218 cub. ft., and has been run as high as 200 revolutions per minute. The three main pipes leading from it are 30 and 24 in. diam: and the smallest delivery pipe is 8 in. diam. The air is used over and over again, and so used, it is said, without any annoyance from the odour of the paint. Running the fan during working hours only reduces the time in which the paint dries by one-tenth. The apparatus is widely adjustable to suit varying temperatures, as either live or exhaust steam can be turned into the heater pipes, and its amount regulated; or the speed of the fan can be varied within large limits, to which end a separate engine 6 in. by 9 in. stroke with steam at 80 lbs. pressure is used to give it motion. The success that attended this experiment has justified Mr. E. B. Wall in extending this system at Columbus to the machine, boiler, and blacksmith shops, and the annular car repair shop. At Bloomington the new locomotive erecting shop is warmed in this manner, the exhaust steam from the stationary engine is passed into an old boiler, through the tubes of which the air is drawn and then delivered into underground pipes, the outlet gratings being at the floor level.

This hot air method was in 1886 adopted for widely scattered shops at Cleveland, O., by Mr. J. Walker (see his communication to the Civil Engineer's Club of Cleveland, 13th Sept., 1887). He used a fan 10 ft. outside diam. with engine 6 in. by 9 in., running from 50 to 275 revols. per minute, the fan outlet being 42 in. square. With underground conduits across the yards, he finds that it requires 1 sup. ft. of steam pipe for each 100 cub. ft. of shop space, the initial air temperature when entering the fan, varying from 100° to 180° F. The conduits are of sewer pipe, the largest diameter of any main being 24 in., and they are trapped so as to get rid of any water that might gather. After the ground had dried there was no appreciable loss by radiation from the buried mains. This arrangement permits the fan and heater to be kept within the boiler house, and the water of condensation to be returned to the boiler at a temperature averaging 180°; but the air is not used a second time, which explains the increased ratio of pipe-heating surface per cubic ft. of space to be warmed. However, the

shops and foundry are kept clear of smoke, the health of the men is all that can be desired, and the system can as readily be adapted to cooling in summer as to warming in winter.

Illustrative longitudinal types of coach and car shops may be seen at the Grand Trunk Ry. works Point St. Charles, and one of the worst specimens of the circular shop, although a very showy building, at Mount Clare on the Baltimore and Ohio Ry. It is 235 ft. inside diam. and fully 114 ft. to top of dome, yet has only space for 21 coach stalls and an inlet track.

GENERAL DISPOSITION OF SHOPS.

What may be called the typical grouping of American railway shops is to place them parallel with each other, and with their longitudinal axis at right angles to the main track (or chief yard siding), with several traverser beds and tables between them. In other words, the shops lie side by side with their gable ends facing the track.

The stalls (or shop tracks) being at right angles to the length of the buildings, or parallel with the main track, if the traversers are set in line with each other, a passage through from shop to shop is provided: that is, it makes a through temporary passage parallel with main track.

Good examples of this arrangement are the St. Paul workshops of the Chicago and Kansas City Railway, and the West Chicago workshops of the Chicago and North-Western Railway, (Plate VII), and it has advantages, one of the chief being, that if sufficient width of land is secured, it permits extensions in length to be built uniform with the existing buildings, without interfering with the ordinary railway work; and when the addition is completed, does not necessarily require a resetting of the machines, shafting or warming pipes, etc. in order to fully utilize the added space.

Until the use of electrically moved overhead cranes changes the shape and size of such shops, does away with the traverser, and alters their relationship to the main track, this grouping will probably continue to be adopted. It necessitates the purchase of a block of land, wide but not long.

One of its most prominent defects is the necessity for skylights. The side walls are so cut up by large stall entrance doors, almost filling the wall panel, that there is little space for side windows except those of limited size, framed into the leaves of the doors; while, as the door openings cannot be kept quite close and tight, in latitudes where cold high winds prevail, these numerous inlets interfere with the comfort and efficiency of the workmen. However, for a correspondingly brief period in

midsummer, the doors thrown wide open are an appreciated luxury, compensating in some measure for the winter inconvenience.

So grouped, the buildings are well isolated in case of fire, as not only does the width of the traverser pit intervene, but in addition, there is a space of from ten to fifteen feet between wall and edge of bed, ordinarily utilized in the storage of wheels and trucks.

A neat and compact arrangement of shops built in the summer of 1887 for the Maine Central Railway at Waterville, Me., is shown on Plate VIII. They are set on each side of a single traverser bed, and occupy but little land. The arrangement will not prove elastic should extensions become necessary.

In new works, buildings are rarely set closer than fifty feet apart: forty will usually fulfil the requirements of the fire insurance inspection, while a distance of thirty five feet has been proved to be far too close for efficient side light even with one-storied buildings.

The new shops of the Panhandle Ry. are set wide apart, with many large trees left standing in between them, forming a pleasing feature to the eye; but even in this country of cheap land, few railways subordinate considerations of economy, to the gratification of an æsthetic taste making the workshops ornaments in a natural park.

In vivid contrast to buildings spaced in this liberal manner, are the works of the London and South-Western Ry. at Nine Elms, London, where the space under the viaduct carrying the four track main line has to be utilized for shop room.

Freedom from snow, giving a wide liberty in roof design, simplifies the grouping of shops in Europe, and in Germany a style of shop not uncommon is one having a continued hip and furrow roof covering about seventeen bays. With sufficient glass (part of it movable) there is no reasonable limit to the amount of light and fresh air admitted, and when artificial heat is necessary, the lack of height in the building, is a help to the warming. In many instances the establishment is under one roof, as at St. Rollox on the Caledonian Ry., Scotland, the area being twelve acres—or the locomotive shops are under the one roof and the car shops under another. The number of trolly tracks and power cranes, and the compact setting, makes the handling of material and work a simple matter.

In plan, the tendency is, for the longitudinal axis of the main building, and the stall tracks, to run parallel with the main track, so that the plot of land required is long and narrow, as for instance in the Norwich new shops for the Lancashire and Yorkshire Ry., the erecting shop of 200

engines capacity, with six parallel tracks and a central machine bay, is 1,520 feet long—almost one-third of a mile.

Although in Canada and the Northern States, shop roofs cannot be a continuous duplication of small pieces, yet the main buildings may have duplicate roofs, that is, a uniform span may be adopted for erecting, machine, boiler, car and paint shops, &c. The Pennsylvania Ry. has so designed and built combined shops, that the portion originally used as car shops, can at slight expense be adapted for locomotive repairs, when the growth in business shall justify the increase of this section and the removal of the car department to another location.

On the general question of grouping, the late A. L. Holley may be quoted. Speaking more particularly of steel works, he remarks "Joliet is perhaps the only establishment where railroads were laid out first and buildings made to fit.....and in designing works, provision only can be made for minimum amount of rehandling and hand labor, by going over all the operations on paper by different arrangements again and again, and not trusting to general ideas to be worked out when it is too late to move a building that happens to be in the way."

For intercommunication, not only between the chief offices and foremen's offices, but also between shop and shop, and each bench and the tool room, electric bells, telephone service and displayed signals to call persons moving about through the works, to the nearest telephonel are daily receiving more general adoption, and their usefulness is so marked, that a single experiment with them is sure to result in their permanent use.

From the Drawings accompanying this paper Plates VII and VIII have been prepared.

Appendix A.

Showing the relative area of Railway shops for Locomotive Department. The first column gives the percentages in comparison with the erecting shops which is taken at unity (100); and the second column the percentage of the total roofed area devoted to locomotive purposes.

Kind of Shop.		Hornesville. N.Y. L.E. & W. Ry.		West Burlington C.B. & Q. Ry.		Scranton D.L. & W. Ry.		Indianapolis G.S.L. & P. Ry. (Panhandle.)		Chicago. C. & N.W. Ry.		Howloh L. & Y. Ry.		Waterville. N. C. Ry.	
Erecting	Percentage of Erecting shop	100		100		100		100		100		100		100	
	Percentage of whole.	29		29		24		14		15		28½		35	
Machine	Percentage of Erecting shop.	100		100		61		*150		200		244		*100	
	Percentage of whole.	29		28½		21		21		30		10		35	
Boiler	Percentage of Erecting shop.	50		63		44		111		73		22½		18	
	Percentage of whole.	14		15		15		15½		11		9		6	
Smithy	Percentage of Erecting shop.	43		63		44		*178		110		13		*20	
	Percentage of whole.	12		15		15		25		16½		5		7	
Tender	Percentage of Erecting shop.					29½				72					
	Percentage of whole.					8				11					
Tool room	Percentage of Erecting shop.	29		10		16		29		15				*11	
	Percentage of whole.	8		2½		5½		4		2				4	
Engine & boiler hse.	Percentage of Erecting shop.														
	Percentage of whole.														
Stores	Percentage of Erecting shop.	29		85		20		100		55		17		20	
	Percentage of whole.	8		20		8		13		9		6½		10½	
Offices	Percentage of Erecting shop.					1						21			
	Percentage of whole.											8			
Flue, copper and tin	Percentage of Erecting shop.							55		36		18½			
	Percentage of whole.							7½		5½		5			
Foundry (iron)	Percentage of Erecting shop.														
	Percentage of whole.											5½			
Paint	Percentage of Erecting shop.											14½			
	Percentage of whole.														

*Starred items give area of combined shop for Car as well as Locomotive department.

Appendix B.

Showing the relative area of Railway shop for Car Department. The first column gives the percentages in comparison with the combined area of both Passenger and Freight erecting shops, which is taken as unity (100), and the second column, the percentage of the total roofed area devoted to car purposes.

Kind of Shop.	West Burlington C. B. & Q. Ry.		Como N. P. Ry.		Indianapolis Panhandle Ry.		Chicago C. & N. W. Ry.		Houston H. & T. C. Ry.		Waterville Maine, C. Ry.	
	Percentage of erecting shops.	Percentage of whole.	Percentage of erecting shops.	Percentage of whole.	Percentage of erecting shops.	Percentage of whole.	Percentage of erecting shops,	Percentage of whole.	Percentage of erecting shops.	Percentage of whole.	Percentage of erecting shops.	Percentage of whole.
Passenger Coach erecting	100	20	100	21	100	17	100	24	100	20	100	23
Freight Car erecting		20		16		17		12		23		18
Paint per both	56	24	77½	30	77	26	68	25	45½	29½	†100	39
Machine (iron)	Loocm. used.	shops	29	11	19	6¼	23	8	23	13½	Loocm. used.	shops
Machine (wood & saw mill)	38	16	27	10	38	13	*24	*13½			41	16
Stores	42	17	17	7			31	11	4	2	13	5
Offices									3¼	2		
Engine and boiler house	5	2	10	4	5	2			2	1		
Dry Kiln			4	1			5	1½				
Upholstery and Varnish					33	10						
Cabinet					29	8¼						
Smithy							13	4¼	9	5		
Tin shop, &c							2	1				

* Includes Cabinet shop. †Includes Locomotive paint shop.

DISCUSSION.

Mr. F. Brown.

One point of the paper on workshops particularly draws attention, "How long does it take to repair an engine?" The author states as an average common in America that heavy repairs occupy 90 days, medium repairs 60 days, light and specific 30 days. The speaker must take entire exception to such an average. If the author, in using the word "America," means that part of this continent called the "United States," the speaker cannot challenge the statement; but so far as Canada is concerned, in his experience, the figures are incorrect. In any properly designed and organized *divisional repair* shop, the limit of time for a heavy repair should be 60 days, it being understood that the author, in speaking of heavy repairs, does not include engines "rebuilt." A medium repair occupies about 30 days at the very outside, and light and specific repairs from 7 to 14 days.

In *main* shops of a large Railway Company with proper supervision, the length of time occupied in these different classes of repairs should be very much reduced. A heavy repair should occupy a maximum of 42 days, a medium repair 21 days, and light and specific from 3 to 14 days. Under these circumstances the author's figures for comparative area of erecting shops would be entirely wrong, and careful attention given to the outfit of the machine shop must considerably reduce the necessary area of the erecting shop.

To show what can be done in well organized shops, a couple of instances may be given. In June, 1886, an order was given to the Canadian Pacific Railway shops, Montreal, to build some Consolidation engines, which were an entirely new class; *a complete set of working drawings* had to be made, all quantities got out, materials imported and otherwise prepared, and the first engine was on the road exactly 90 days after receipt of the order.

Later on, in June, 1887, the same shops received an order to build some 17″ × 24″ road engines, for which all materials had to be procured, some of them imported, and the first engine on the order was on its trial trip 77 days after receipt of that order. These statements are merely advanced to prove what can be done and what is done in Canada, and are not puffing advertisements such as were published lately in an American Railway Paper, stating that in the Altoona shops on the Pennsylvania Railway, a locomotive was "erected" inside of 17 hours. Illustrations of this performance were distributed freely, and the reci-

pients were asked to place this absurd assertion in a conspicuous place. Practical men know this performance to be utter nonsense, so far as "erecting" in the true sense of the word is concerned.

The speaker also desires to ask the author to explain why he calculates on four or five per cent. of his motive power being in the yard, "waiting to come into the erecting shop for general repairs." If the shop is properly designed, where is the necessity for any engine to be kept waiting for repairs? This provision is one which it seems difficult to account for, and it calls for explanation.

Mr. Wallis. He was glad to note that the author expressed preference for the "longitudinal" type of running shed, and fully endorsed his remarks in reference thereto.

On the Grand Trunk Railway, there were but two exceptions to the circular type of shed or round house commonly so called, both referred to in the paper.

The one at Montreal contained five tracks, and accommodated twenty-five engines, while that at Lindsay had four tracks and was designed for twenty engines.

The larger of the two with its approaches, iron turntable standing outside, water service pipes, steam warming arrangements, sand house and tool store, cost about $50,000.00 or at the rate of $2,000.00 per nominal engine accommodated.

The sheds were built in some degree as an experiment, but from his experience elsewhere with similar ones he had little doubt when he designed them of their being successfully worked.

The round house with some advantages had one serious defect. If built of wood with the usual felt and gravel roof, so common in Canada, it was unusually liable to take fire, and he knew of an instance when nine locomotives were burnt almost beyond recognition, it having been impossible to extricate them from the shed whose exit was controlled by a central turntable.

The same defect was also forcibly apparent in case of accidents which occasionally happened to turntables, and he was sure that many Railway officers could recall instances of annoying delays resulting from this cause, which could not have occurred with "longitudinal" sheds and outside turntables.

It would also be readily understood that while a round house could only accommodate the specific number of engines for which it was designed, a long shed constructed with the same length of standing room could house a percentage beyond that number, varying with the length

of the engines and the number of parallel tracks within it. In severe weather this was an important consideration, and when tank engines formed part of the equipment, additional accommodation of twenty per cent., or say one engine per track, might be obtained.

The difficulty mentioned by the author in the arrangement of the engines for prompt despatch did not exist, or at any rate was not felt in practical operation.

He thought it likely that the author's estimated cost of $1,000.00 per pit for round house did not include water service pipes, and arrangements for warming and turning engines; but, setting aside the question of first cost, the only advantages which he had been able to discover for that type of shed were those of better light and more convenient location.

Skylights were not satisfactory because they were difficult to keep clean, and subjected the roof to unnecessary chances of decay, and it was clear that the distribution of light from side windows was better in a circular shed.

As to location, angles or corners were often formed in large yards by the leads of the sidings from the main line, and these corners made convenient sites for square or circular houses, when otherwise the adoption of the long shed might be attended with loss of ground space.

In regard to repair shops, he noticed how widely different, on different railways, was the division of the total floor space among the various shops. The tendency seemed to be towards unduly large erecting shops, and this might explain the rather high average given for engines under repairs. The average for the year 1388, for all classes of repairs on the Grand Trunk Ry., was 35 days, but he was sure that this could be still further decreased with the aid of a liberal expenditure in the direction of the machine shop.

The division of time as between engines under heavy, medium and light repairs, was somewhat different from his experience, but as the character of the repairs might vary widely in various shops, it was difficult to establish an exact comparison. He thought that 130 days, 12 days and 3 days, was more nearly the average under the heads mentioned, when the heavy repairs constituted for the most part an almost entire reconstruction, and included a new boiler, and perhaps new cylinders, with time allowance necessary for painting and to allow for the delay caused by waiting for materials, a large quantity of which it was not usual to keep in stock.

Heavy repairs such as he had indicated would enable an engine to endure three years work, with perhaps an intermediate medium repair,

consisting of retubing and turning tyres, so that not more than 14 or 15 per cent. of the stock need be out of the service on this account.

He was aware that under favorable conditions, and with special effort, much better results could be obtained, and he had in this manner turned out new engines at the average rate of one every eight days, for a whole year; but this was exceptional in railway works largely engaged in extensive repairs, which, he might add, required more labour and longer time.

Light repairs, in his nomenclature, were such as could be executed for the most part in the running sheds, and consisted of rebushing outside connecting rods, closing brasses, facing valves and seats, and changing truck and tender wheels.

Referring to the question of the foundry, he said that the foundry at Montreal on the Grand Trunk Ry. was an old engine shed of the cruciform type, which answered the purpose remarkably well; the radial cranes swung from the inner angles. He might have preferred to use overhead cranes, but the roof was not high enough to admit them.

Mr J. Harkom A review of the very full information contained in the paper under discussion has led the writer to believe that more attention might be given to "Location," and that the remarks of the author on acquiring a sufficiency of land are worthy of being followed up.

The necessity for "elbow room" has been so frequently shewn by the growth of railway enterprises far beyond the views of their promoters, that it may fairly be assumed when new railways are being constructed they will in the future (more or less remote) require, for their rolling stock and other equipment, more facilities than are needed when the railway is first constructed, and which for the simplest reasons are made as small as can be considered consistent with the requirements of the business expected on the road.

The question of land is one which lends itself to a different method of dealing, compared with the construction of works, and is one to be treated from an entirely different standpoint.

Works of any kind which might be constructed in advance of immediate requirements would not only lock up unnecessary capital, but deteriorate and cause expense for repairs.

On the contrary, land always has been, and always must be, so long as proprietorship in it is recognized, a good investment in such localities as those under consideration, returning good interest on capital invested, and never being cheaper than before the railway is built.

The instances of cramped sites given by the author show the advisability of the policy advocated wherever it is practicable.

The creation of new shops on a line already built is subject necessarily to somewhat different conditions, but the same principle should govern.

The disposition of shops in large works, such as noticed by the author, appears to the writer of the very first importance, and the latter endorses heartily the principle that the general plan should be rectangular rather than those referred to at Frankfort, N.Y., and Plattsmouth, Nebraska.

A great argument in favor of the rectangular system, is that all the area of the works can be more fully utilized in that way than by any radial arrangement, and the possibility of communication from shop to shop is of very great benefit in works of the kind, especially in locomotive shops, which, in the writer's opinion, should run as described by the author.

In car shops, on the contrary, their length should be in the direction of the main tracks, or so that they can be readily shunted by means of sidings from them, the idea being that in the case of passenger cars, whole trains should be turned out together, as is regularly done in England and in many cases in the Grand Trunk Railway shops at Montreal.

The supposed difficulty, noticed as such by the author, should never exist if a proper knowledge of what is required to be done to each car has been obtained before it goes to the shop, as should be the case, and what better opportunity is afforded for sorting cars than the sidings leading to such a shop as described, with six or seven tracks? For it must not be forgotten that the sorting of cars has to be done, whatever kind of shop is used.

The transfer and turntable are not only higher in first cost than common sidings, but are more expensive to maintain, more cumbrous and slow, where so many more cars have to be handled than engines in the shops, the objections on that score not being of so much importance in the case of the latter. More cars can actually be worked upon in a longitudinally arranged shop than in the other kinds, thus reducing the area to be roofed and walled, to say nothing of warming in a cold climate. This is applicable to both freight and passenger car shops for erection; while for car machine shops, both for wood and iron, the benefit in rapid handling of the bulky material used in them, through the use of tracks parallel to them and easily accessible, is very great.

An important consideration in the location and general disposition of car shops is the ready reception from and delivery to traffic of the cars.

The approaches to these shops should never be hampered, or the result will be a pecuniary loss, by cars being kept from traffic when they are badly needed.

To return to the locomotive shops, the writer is under the impression that the author, while giving many examples, has not laid down, in a sufficiently clear manner, the order in which the several shops should stand, nor the location of that very important establishment "the stores," and with that idea suggests the following as embodying principles, the neglect of which affects in an unfavorable manner the working expenses.

The fact, that in large works, every time a piece of work is handled, it costs more or less money, should never be lost sight of, and that system is the best which provides for the fewest handlings outside those absolutely necessary for manufacture and treatment in the different processes.

All material should be delivered at the stores, weighed, measured, and tested by officials of that department.

The stores should be located in such a position, that easy access can be had to them by tracks and waggons.

The object of the works being to turn out finished articles in the shape of engines and cars, the store should be placed between the two sets of shops, with the idea that raw material supplied from them should issue in the shape of finished work at the opposite end of each set of shops.

The shops handling the heaviest material should be nearest the stores, therefore the first shop in the locomotive series should be the boiler shop, then the smith's shop, the machine shop, wheel shop, erecting shop, tin shop, and paint shop in the order in which they are named.

Lumber being a special article of large bulk, and necessitating a large stock, should be kept in its own yard a considerable distance from the works; but access to it should be readily had from the main tracks.

The position of the Foundry is much the same as that of the stores, and should be located as near to both locomotive and car shops as possible.

Two tracks should run the whole length of the works with frequent cross-over switches and connection to the transfer table in boiler and erecting shops, if such is used; and by the simple precaution, in first laying out the shops, of establishing the floor levels two feet above the mean out-door level, which will ensure dry ground around the shops, the traversers may be worked out of doors, even in Canada, so saving the extra roof referred to by the author.

Where the traverser can thus be used, it is, in the opinion of the writer, far preferable to the overhead crane system, which calls for construction of the shops in a much more expensive manner than the traverser system.

A very vital requisite in all large works is a good and effective system of drainage, with easily accessible manholes at junction points.

If possible, the water pipes should be laid in such a way that breaks can be attended to without cutting off the whole supply of the works. This can be done by double mains, and the laying out of sectional areas, which can be cut off separately if required.

A very important question is that touched on by the author, under the head of transmission of power, in the last two paragraphs.

The location of boiler houses is an important one, and the writer is of opinion that by the careful building of steam pipes, with provision for their expansion (not necessarily of the gland pattern so frequently used), and protection from radiation, steam can be economically carried long distances.

The use of one large engine to drive a large quantity of machinery in such shops is not so good as a number of small engines, each working its own group of machinery, and therefore the construction of central boiler houses, with track accommodation for the handling of fuel and refuse, is a good arrangement.

The writer has so far treated the supposed works as situated all on one side of the main works tracks; and it having been assumed that the whole have been laid out, the tracks included, on fresh ground, these would of course have been placed in the centre of the plan.

The occupation of the other side will now be considered, and it is there that the Foundry, stationary boilers, and such shops for the manufacture of permanent way materials, should be located, with such sidings as are needed for all these works.

The locomotive yard should be on the same side as the erecting shop, to which, if it can be so arranged, there should be two tracks or sidings one for the delivery of new boilers and engines for repair, and the other for the exit of the completed engines *en route* to the paint shop.

Engine or running sheds are a different class of buildings, and necessarily vary, as shown in the paper under discussion.

They should be always located at a distance from the works so called.

The importance of being able to enter or leave at opposite sides or ends cannot be too highly rated, whatever be the shape of the house, whether annular or rectangular.

This was evidently understood in the case of a rectangular shop at Cardiff, mentioned by the author; and, if necessary, the writer thinks that a loop around a shop should be constructed to gain the end desired, which is to allow engines to be regularly and, in cases of necessity, promptly turned out for service.

Whether the shop shall be of the general annular shape or rectangular is not of such great moment, intelligent supervision and handling will give good results with either, while in case of fire, the rectangular type has great advantages over the other, and is not dependent on the turntable to empty it, should the latter break down, which, as a piece of machinery, it is liable to do.

A very valuable addition to the usual plan of covering these buildings is a double roof, which successfully prevents condensation in cold weather, and also prevents the formation of icicles. A shed roof repaired last fall (1888), under the supervision of the writer, has given excellent results during the last winter, and justified the expectations formed of it.

The old roof was a flat one, a little over half an acre in extent, covered with the ordinary gravel and tar felt.

The gravel was all scraped off the felt, which was patched and repaired with Sparham roofing material, where such was necessary, after which four-inch scantlings were laid, and common boards laid on them, the ends being partially closed by overlapping at eaves, in order not to entirely prevent circulation. The building was then handed over to the roofers, who readily gave a ten years' guarantee for the roof, the contractor telling the writer that his experience of double roofs was that he had no repairs to do to them, the action of the weather, snow ice, &c., being practically reduced to the very lowest possible point.

As an economy in this direction, the writer is satisfied good results will follow, while the extra expense will be scarcely felt.

For slate on pitch roofs, the writer, as mentioned by the author, has had excellent results by laying the slates on strips pitched the right distance apart, three winters at Arthabaska having failed to show an icicle on the eaves, and others since built give the same result. Slate on a pitch roof of one in three and a half has been successfully laid by the writer on fuel sheds, and this winter he has seen the snow slide off that roof.

The slate mentioned by the author is unsurpassed in quality, and the writer took steps to compare it with English (or Welsh) slate when in England, in 1886, at the "Colinderies," the comparison being in the highest degree favorable to the Canadian.

On the subject of ventilation the writer would like to make a few remarks as to the material and construction of ventilators, which he holds should be so constructed that in cold weather condensation on their sides should be avoided.

The use of iron has the effect in cold weather, of creating a conflict

of currents in all iron ventilators, which the writer has found is not done when wood is used, the sides being doubled and an air space left around them.

The painting of the insides with fireproof paint makes them perfectly safe, while a down draught never takes place in them. The writer has in cold weather seen vapor descend on an iron ventilator, and directly pass to and out of a ventilator made as described of wood. A number of these are in use on engine sheds, placed there under the writer's supervision, with good results, and they are in use on the roofs of the smith's shop and foundry of the Grand Trunk Ry. at Montreal.

Mr. Atkinson.

He took exception to the vague title of the author's communication, which he thought might have been more correctly entitled "Railroad Shops," as it had reference to them only.

Basing his remarks upon the different headings as they appeared in the paper, he referred first to the foundations, and asked what protection was provided for iron pillars run down below the floor level, as he thought they would be liable to rust if the ground was "made." It was probably a cheap way of building a shop, but he doubted whether the maintenance of the pillars would be economical.

In building up the supports for the rails, he noticed that the system of iron girders had been adopted at the Stratford shops, and asked if they were supposed to make the side of the pit, because if so, the space below would require filling up, of which, however, there was no mention. No doubt the result would be a very good floor, and one on which engines could be easily moved about when required.

Nothing was said about the pits, and as he had seen some of very bad construction, he would like to hear from the author on the subject. He knew nothing worse than pits made with a concave floor; they were inconvenient and costly to maintain, and the workmen often stood in water unless there was a good system of drainage.

He advocated a convex floor with a brick set down at each side about 4 inches deep, to act as a gutter, which, would render it much more pleasant for men while working and easier to keep in repair, as it could be taken up at any time without interfering with the rest of the flooring.

As to the walls, roof trusses ought to be supported upon heavy pilasters, and no one could afford to build anything more than a light wall between. The heavy pilasters put outside the wall took up a considerable amount of room which might be used for shop room, if put inside, in which case they would also be useful in erecting or machine shops, for carrying crane ways, etc.

Referring to engine houses, it seemed that the author had contemplated a flat roofed engine house, with an outer ring much higher than the inner one, causing the slope of roof to be inwards. Most of the roofs he had seen sloped outwardly, giving a roof 6 or 8 feet lower at the outside than if sloped inwardly, and as in cold climates like that of Canada, the number of cubic feet of air to be heated was a consideration, he was of opinion that the best results in this respect would be obtained with a roof sloping outwardly. There was usually sufficient light for most purposes with an inner wall of wood and glass; but if more light was required, a half mansard type of roof with windows above would supply the deficiency.

The author had referred to the cedar foundation posts, 6 or 8 feet apart as "carrying a mudsill." This, the speaker presumed, was a misprint and should have read, "placed upon a mudsill."

The system of roof adopted by Mr. Harkom, would give great freedom from icicles, which were alike destructive to the engine house roof and walls; but he was of the opinion that the slates would easily be blown off if subjected to strong winds, and that, unless there was a blockade, there would be great liability to fire from the depositing of sparks.

The rectangular style of engine house was not much used in Canada, although it would probably give the greatest amount of satisfaction when the ground covered and the cost were taken into consideration.

The "Oil House" and "Sand House" might have been omitted from the paper, and more space given to the details of shop building. For example, the class of roof and the material and construction of the same had not been touched upon. He had no doubt that the area of the erecting shop (as he had since been informed by the author) was a good average for the American system of repairs, but he wished the author had given some information as to what could be done in regard to the output of engines for a given size of shop, because there was no doubt that the time given would demand a larger shop than those of modern construction.

Deep traversers or transfer tables were generally admitted to be more of a nuisance in a shop than otherwise, if they could be done without, and were therefore made as shallow as possible.

He had seen one of a new pattern mentioned in the Railroad Gazette, as being adopted by the Pennsylvania Ry., but did not know whether it was used inside or outside. It was 60 feet long, and he did not think it would be necessary to put a traverser of that length in a shop for engines; but if used for coaches, it would not be long enough for the later

and larger classes, and the design was too deep and heavy to be economical.

The systems of obtaining power for traversers were so various, that it could scarcely be a present subject of discussion. Everyone used just what they thought suited best.

The remarks on overhead travelling cranes led the speaker to think that the author was much in favor of their use, although he did not say so. From his experience, he should be very sorry to be without them. A break down with an overhead travelling crane was as bad as having 20 or 30 men away from the shop, and it was impossible to get the same amount of work done on the same floor space without cranes. They were handy alike for moving heavy and light weights, saved an immense amount of time, and were not liable to cause accident to the men working around.

Of the cranes under the speaker's direct charge at the Canadian Pacific shops, the speed of the slowest is 2½ feet per min. raising, and 3½ feet per min. lowering; the next being six feet per min. raising, and 7½ feet per min. lowering; and the quickest 17 feet per minute raising, and 22 feet per min. lowering, suitable for all light work. The travelling speed is 60 feet per min., and the traversing speed of crab 40 feet per minute.

They were made by Craven Bros., of Manchester, who were among the best manufacturers in England for good and efficient work. The capacity is 25 tons; each has a single crab with double chains to the lower pulley or hook, with three speeds of lifting and lowering as before mentioned. The span is about 55 feet, rail to rail, and the cost about $3,000 f.o.b. Liverpool; tramways and cost of placing in position being of course additional items. They occupy 8 feet in height from the lower side of the cross girders to top of the crab, are supported upon cast iron pillars, and are driven by 1¼in. manilla rope, running at a speed of 2,500 feet per minute.

In cranes with two crabs, the chains have to be so long, that the wear and tear become excessive, and the danger from broken links much greater.

In the matter of driving power the author seemed to be in error. At the Canadian Pacific shops they had been using a leather belt which had been in service for 5 years, but having now given way it was being replaced by a rubber one.

It was almost impossible to discuss the subject of machine grouping without a plan of the shop, giving the location of the other shops, and information as to the delivery of material, and whether or not cranes were used in transferring the same.

He has under his charge a single rail crane of Ramsbottom type, with a capacity of three tons, and a radius of 13 feet, which is of great assistance in moving heavy weights about the shop, and which enables them to do a large amount of work in the course of the day. This crane travels at a speed of 44 feet per minute raising, and at 6½ feet per minute lowering, the driving rope being ¾ in. diameter and travelling 1,500 feet per minute. He does not know that it is preferable to an overhead travelling crane, but it is much cheaper for the amount of service it gives, and does not take up much side room.

In placing machinery in a gallery, it should be located down the two sides, as this plan would give greater facilities for the storage and transfer of work than a passage down each side of a double row of machines, by which method a wider gallery would be required, in order to get an equivalent amount of work done.

Referring to the foundry, the author says that a most convenient plan is to divide the surface to be roofed over into two sections of about equal length and span, placing them at right angles to each other. He did not know whether the author intended this to be of cruciform or T section, but did not think that any one in designing a new foundry would build it similar to that at Point St. Charles which would not permit the use of an overhead crane, probably the best piece of machinery that could be put into a foundry. Sellers of Philadelphia had replaced radial by overhead cranes, and he had been informed that the change had given great satisfaction. It appeared that there was considerable loss of ground and a good deal of expense in building a shop of the kind mentioned. The same length of wall would cover almost twice the area if built in the form of a complete square or rectangle, with only a slight addition in the cost for roofing; and he thought that the author's idea of a foundry would bear considerable discussion before being adopted.

In a brass foundry one of the most important requirements is a good draught, or something to take its place, in order to shorten as much as possible the time required for melting.

In the smiths' shops, no doubt many were using the central smoke flue referred to by the author. He had got rid of a smoky shop by making the roof a better type of ventilator. The ordinary single span roof with a clere-story open below, and having louvre sides, was not adapted for getting rid of smoke. The louvres allowed snow to blow in, and the air could not get out freely, causing the shop to become full of smoke. He roofed up the principals of the main roof with boarding to within about two feet of the ridge pole, leaving the clere-story

open at each side by taking out the louvres, and made a ventilator of it along the whole length of the shop. He came to think of this method by observing the new Canadian Pacific Railway station on Dominion Square, which had a clere-story roof open at the bottom, and with which there was invariably a great deposit of snow, and the smoke did not get out as it should do. If the roof were boarded up to within a short distance of the centre, the smoke would pass out through the opening.

The speaker here illustrated his improvement on the blackboard, and said that if the roof boards were continued to within about 18 in. of the centre, and the louvres taken out, the snow would blow right across without having the opportunity of dropping down into the shop, and a suction of smoke would be produced at the side.

The roof was the same as before, held up by ordinary supports, and boarded across in sections of about 15 ft. When there was no wind the heated air went out of its own accord, while the cross boarding prevented the wind going down into the shop, no matter which way it might be blowing.

He had an excessive amount of smoke in one of his shops from two large furnaces in addition to small ones, and the first result of his arrangement was the removal of the sulphur which had given them much trouble, the smoke following it away.

He had not attempted to reduce the amount of suction, simply leaving it open. The clere-story was left exactly as before, and he boarded up within about 2 ft. from the centre of the ridge poll.

While speaking upon this subject he said he intended to try his system of ventilation in a shop which it was necessary to keep warm at night, and in doing so he would put rising and lowering doors, one on each side, so that when either was raised it would act as a deflector. In this way he felt sure he could clear a smoky shop in 20 minutes.

The author's remarks on the boiler shop were too meagre for the speaker to take exception to, or to agree with. This shop was the most difficult of all to deal with, both as to the handling of material and the bringing in and taking out of work, and would of itself form an excellent subject for a paper.

The author had said little about the arrangement of tools or what system of cranes should be most freely used. In the Canadian Pacific Railway shops there is a radial crane worked by hydraulic power which is found to be very serviceable. It had given some trouble in the past, but it now proves most efficient.

A plank flooring was generally used for both machine and erecting shops if possible; but sometimes earth was used, and iron borings with salammoniac made a good covering for an earth floor, as it became hard as asphalt.

A type of roof which he considered very suitable for a longitudinal engine shed is one having clere-storys 8 or 10 ft. high, with windows in the sides; considerable light is admitted, the shop can be easily heated, and the cubic capacity may be as small as possible. If the shop was wide enough for five tracks, the middle track could have a row of posts down each side forming a clere-story. One row of posts in each of these spaces would not amount to much, and the roof could be of cheap construction, making up for the extra space required.

He was not surprised at Mr. Brown taking exception to the time occupied in making a heavy repair, and 130 days—as quoted by Mr. Wallis—astonished him. He accounted for the difference between that and the time mentioned by Mr. Brown, by the fact that the Canadian Pacific shops were well supplied with machinery, being laid out for building shops, and containing probably on that account a larger quantity of machinery than was found attached to most erecting shops. An engine coming in badly damaged would frequently be turned out in six weeks, probably with repairs to boiler, and new fire-box.

About 50 per cent. of the Canadian Pacific locomotives were of foreign construction, and these were sent to the shop for repairs as often as engines of their own build. They did not hesitate to replace the details of such engines by standard details, although this was not often done, as their stock was extremely small, and they were more frequently handicapped waiting for castings from outside than for what they could make themselves. For forgings only, an engine was not delayed long, and if a new set of wheels were required, but a short time was taken to turn the engine out if the wheels were on hand, but they were generally delayed waiting for castings.

In the time occupied in building the Consolidation engine at the Canadian Pacific, there was a delay of nearly two weeks waiting for castings, and the total time taken was the very shortest they could possibly make it. A complete set of drawings, as understood in a building establishment, had to be prepared, and this was done with a very limited staff in the drawing office in 2½ months. Their foreign built engines were constantly coming into the shop for new cylinders. They had exceptional advantages in their shops from their system of cranes, which could only be appreciated by those using them.

Mr. MacPherson.

The Society is indebted to Mr. Barnett for a most valuable paper, which must have taken some time to prepare if the author has not more spare hours than most railway officers.

The writer had hoped to have been present at the discussion, but was prevented by business, and the following remarks are submitted, though not at all commensurate with his interest on the subject.

The experiment referred to as carried out by Mr. Harkom, to get rid of the icicle formation on the eaves of an engine house, would appear to be an expensive method, though correct in principle.

The same end was attained with comparatively little expense, in an engine house erected under the writer's supervision, at Hochelaga, in 1886, by building a few pieces of 2 in. diam. iron pipe into and through the walls, just under the roof at the gables.

Several brick engine houses built on the Canadian Pacific Ry. previous to this, without these air holes, have given great trouble, on account of the icicles backing the water up under the eaves and ruining the walls. The one referred to at Hochelaga has given no trouble in this respect, and the icicle formation is very slight. At the same place may be seen a 65 foot wrought iron turntable, which length does away with the frogs leading to the engine stalls; the angle being 9 degrees between centre of pits.

It would appear that the American practice of radial engine houses and turntables is preferable to the English or longitudinal type, at all points where time is any object, and it would be interesting to know how the English officer mentioned, turned his engines when handling 400 train engines daily at one terminal; if they were turned on a "T," it would certainly take more time than on turntables, and his bare statement that he could not have done the same work over turntables, until the definite time consumed in turning is given, seems far from conclusive.

In regard to the engine house at the Canadian Pacific station, the sides of the double roof are not finished. Mention has been made of the snow blowing in. It was proposed at present to put small windows all around, which could be closed in time of snowstorms, without interfering with the light. They were to be opened and shut by a small chain running along the side of the roof. The slat system could not be made to keep the snow out, and also afford an exit for the smoke.

Mr. Peterson had received several letters from different railroad companies, with various plans of slats at the side of louvre roof made of sheet iron, but they all said they could not ventilate and keep the snow out at the same time.

They made several designs of roof, but found it was no use trying to do so and put in windows. Mr. Atkinson's plan appeared to be a good one; it allowed of a through draught acting something like an injector.

Mr. Barnett.

Mr. J. D. Barnett, in replying, said that no one better appreciated Mr. Atkinson's criticism than he did. He admitted that the title of the paper was vague, and that he might perhaps with advantage have enlarged on some points and cut down on others. He thought, that almost all, who had attempted a comprehensive paper of the kind, set out with a general idea of what they wanted, and as the work progressed, it could be noticed that they were apt to give more attention to those points in which they were more particularly interested; but even if wanting at some points, he felt like apologizing for the length of the paper. When persuaded into writing it, he intended including the workshops of American firms exclusively building locomotives, making a special point of giving the relative proportions the various shops bore to each other; but finding it was difficult to get complete information, he had to give up the idea, and the communication resolved itself into one on Railway Workshops, the so-called "erecting shops" being dealt with only in reference to locomotive repairs.

Replying to Mr. Atkinson, he did not see why the corrosion should be excessive in pillars which were carried down below floor level. There should not be and, as far as he knew, there was not any excessive corrosion. If a pillar were properly coated with tar, and the earth not often disturbed, the corrosion could not be such as to lessen the strength of the pillar. So long as iron was deep enough below ground to exclude atmospheric air and was free from actual contact with water, oxidation was not excessive.

Evidently there was some misunderstanding about the pit rails at Stratford, which were intended to carry the traverser upon which the locomotive was moved from one end of the shop to the other, and not for the engine pits, the sides of which were brick with a timber sill on the top.

His experience with pilasters inside the walls was that it resulted in a dirty and untidy shop. The dirt accumulated in the corners, and workmen piled there the old material and scrap, so that altogether it was difficult to keep the shop neat in appearance.

A pilaster, too, would cut off part of the light. It was a convenient arrangement to run the workmen's benches down the side wall close to the windows, and pilasters would cut the benches off

into short lengths of 16 or 18 feet, although with benches there would not be quite the same temptation for workmen to place scrap and refuse in the corners. One of the most untidy shops he had ever seen was one with deep inside pilasters.

The "mud sill," technically speaking, was the lowest timber, the one on which the posts rested when a timber post foundation was used. In Ontario, however, it was common to call the sill on which the upper frame rested the mud sill, and he had used the vernacular rather than the strictly correct term.

That the space between the double roof should be a fire-trap was not a necessity. An opening between the two roofs could permit the passage of a current of air through, and yet the edges might be blocked so that sparks could not get between them.

The suggested area of erecting shop did not exemplify the very best modern practice for a railway whose rolling stock was uniform. He had given some figures, showing what he thought should be the comparative size of the erecting shop. He would have liked to divide the floor space of the erecting shops given in the tabular statement, by the number of engines owned and repaired by the various railways, so as to show that they fairly corresponded with the floor surface allowed in the ten pit erecting shop reduced from the mileage figures given; but the information could not readily be obtained.

The figures he had given, shewing the number of days an engine was under repair, were not far from average American (United States) practice, especially in the case of the erecting shops of those railways on which there was a large variety of locomotive stock, and in which the number of machines and the machine shop surface was limited. It was comparatively easy for railroad officers to persuade their board of directors to give them additional roofing, but it was often a difficult matter to get their sanction for the purchase of modern machine tools, and as long as they were limited in the number and efficiency of their tools, an engine must necessarily be a long time in shop.

Why Mr. Brown, in this statement, should have excluded *rebuilding*, the speaker did not understand, seeing that it was a factor in every-day work, and as much a necessity during the year as the doing of medium, specific and light repairs, and therefore must be allowed for in any average of work to be done or of floor space upon which to do such work.

He had worked out the time average for the Stratford shops of the Grand Trunk Railway for the whole year ending 1887. All the labour

being devoted to repairs (the rebuilding being done at Montreal), the figures were :—

76 engines received heavy repairs, occupying an average of 62 days;

21 engines received medium repairs, occupying an average of 29 days; and

37 engines received specific and light repairs, occupying an average of 20 days.

Since that date Stratford shops had been largely increased, and were now in full swing. For the sake of comparison he had worked out the figures for the six weeks, since the establishment had been enlarged and fairly equipped with machinery and tools, and found them to be as follows :—

11 engines received heavy repairs, occupying an average of 92 days;

12 engines received medium repairs occupying an average of 32 days; and

16 engines received specific and light repairs, occupying an average of 23 days.

The figures covering so brief a period were of course only approximate, nothing else could be expected under the circumstances. Such figures, he believed, had never before been published, and he had hoped, by putting such information together as he could obtain, to provoke some such discussion as had taken place. He hoped and expected to learn something himself as one of the results of the discussion.

It was undoubtedly the case, as had been remarked, that the question of actual machine grouping depended upon the shape of the shop and the number of cranes, etc.; but the point he desired to make clear was that when they had very few hoisting tools, cranes, and overhead travellers, it was necessary that all large tools handling bulky material should be grouped close together. Since the general adoption of cranes and the liberal use of overhead hoisting tackle, however, it seemed to him that that necessity had disappeared because of the ready movement of heavy masses; whether the weight was two or ten tons and the distance five or thirty feet, it made little difference in moving it about the shop when the material was once suspended. The result of this had been that in the modern shop there was a tendency to group tools and machines of the same kind together, and in that way to minimize the attendance required at them, thus effecting a decided saving in the cost of labour.

The speaker then illustrated on the blackboard from existing practice several ground plans of foundries, showing how in the form of right angle building recommended, a single jib crane would sweep the major

part of the whole floor, but that if overhead traversing cranes were provided, either a square or rectangular building was the best, while for convenience in clearing the cupolas and yet handling the metal buckets to advantage, the traversing girders of the crane should lie parallel with the line of the cupolas.

He was much pleased with Mr. MacPherson's communication, showing how he got rid of icicles; apparently he trusted to an out-flowing current of warm air at the level of the eaves, to melt the icicles, or to prevent their formation. If that would always do its work, he considered it one of the most valuable hints he had received that evening. He had been troubled much with icicles in a shop 120 feet wide, and if such a simple expedient as allowing a fine current of warm air from the shop to play upon the icicles was always successful, he felt much obliged to Mr. MacPherson for the information.

The statement made by an English railway official, that he would have great difficulty in handling 400 engines daily if his engine sheds had been annular, was impeached by Mr. MacPherson. The speaker said the point the officer made was, that although he had to turn his engines on the turntable, the rectangular form of shed permitted him to turn his engines outside and get them exactly right in position to take out their next trains shortly after their arrival at the shed, and nine or ten hours before they were due outwards again; whereas, had he an annular engine house, he could not have got the engines turned and into position by train time, at certain busy hours of the day, without taking them from the protection of the engine house, and leaving them outside, which would entail extra siding room where space was valuable. The engine in both cases would have to be turned on the table; but the advantage with the rectangular shed was that this could be done so many hours before train time, without putting the men in the running shed, or those who had to do shed repairs, to any inconvenience.

Mr. Brown's information, as to the brief time in which an engine could be built, was interesting, but had no reference to any matter mentioned in the paper. He (Mr. Brown) did not understand why 4 or 5 per cent. of the engines should be "waiting repair." That was scarcely what the paper said. In trying to discover what proportion of engines could be counted upon to be in steam daily, the speaker had given the matter some consideration, and found (as everybody else would find on going into the matter) that there were a few days lost, from the time an engine left the erecting shop until it was in condition for handling traffic. If the pit room in the erecting shop was limited, the painting should not be done there, but in any warm build-

ing which needed to be only of simple construction; and if the most was to be made out of the erecting shop space, the engines should only be *repaired* there, and moved into a building (similar to that mentioned) for painting and finishing.

From what he had said, it would be seen that a portion of the rolling stock would not be actually under repair nor yet actually in traffic. Engines sometimes had to wait for pit room or for painting, and there was nearly always something being waited for, causing a certain proportion of engines to be out of service. He was still of the opinion that 4 to 5 per cent. of the total stock would be in that intermediate state, not absolutely in the erecting shop occupying pit room, nor in the round house ready for traffic, and this contingency had to be allowed for in getting at the desired estimate of the mileage that would, under ordinary conditions, be obtained from 100 engines in a year.

The figure of $1,000.00 per engine stall did not include pipes and other internal fittings. The first part of the paragraph in question described the most primitive form of section of annular engine-house found on this continent; and in giving other prices, the speaker had adhered to the primitive type of construction, adding, however, a little more stability. The price quoted was for a simple brick shed with stone foundations, no allowance being made for water pipes or steam pipes, etc.

Supplementing his remarks as to a central turntable in the annular arrangement of shed giving trouble, the author had a very lively recollection of one of them breaking down at a station under his charge at 2 o'clock in the morning, about one hour before the passenger trains concentrating at that junction were due. Every passenger engine was locked up for nearly ten hours, putting the Traffic Department into great disorder. Such a serious mishap did not often occur, but it was a rare thing for a district officer to go through a winter without some failure to a turntable, although they were made of the best material and design. Of course with a longitudinal type of shed, a turntable was necessary, and it was used in putting the engines into the shed ready for traffic; therefore, until every engine in the shop was cleared out, no great inconvenience from the break-down of a turntable would be felt. There was plenty of lee-way with a shed full of engines, during which time the accident could be made good. In the case he had mentioned, passenger engines and every other kind wanted were unavailable; shunting engines had to be used, and some engines were run tender first.

Mr. Harkom had given an ideal plan of the grouping of shops and of their relation to one another. The author at first intended basing his

communication on an arrangement of that kind, but afterwards considered that such a course would be of less interest, and would not provoke so much discussion as if the matter were dealt with as it existed under the limitations of actual practice. The drawings exhibited and the figures given in the appendix illustrated quite modern practice.

Mr. Harkom had stated that traverser tables could be worked out of doors during a Canadian winter. The speaker was sorry Mr. McWood was not present at this discussion, as he would have been able to tell them about the trouble he experienced at Point St. Charles some 18 years ago, in endeavoring to handle a traverser in the deep snow and low temperatures which generally accompany a Canadian winter.

In his ideal grouping of shops, Mr. Harkom advocated placing the Locomotive and Car establishment on one side of the track, and the Engineer Department shops on the other side. This was rarely accomplished, and the better plan was to have all workshops on one side, and the village and residences of workmen with the station on the other, so that the workshops and residences of the workmen might be within reasonable distance of each other.

Thursday, 28th March.

HERBERT WALLIS, Member of Council, in the Chair.

The following having been balloted for was declared duly elected as

HONORARY MEMBER.

SIR CHARLES AUGUSTUS HARTLEY, K.C.M.G., F.R.G.S.

The discussion of the paper on Work Shops, by T. D. Barnett, occupied the whole evening.

Thursday, 11th April.

P. A. PETERSON, Vice-President, in the Chair.

The adjourned discussion of the paper on Cantilever Bridges, by C. F. Findlay, occupied the whole evening.

Thursday, 25th April.

P. A. PETERSON, Vice-President, in the Chair.

Paper No. 30.

THE COLONIAL GOVERNMENT DRY DOCK, ST. JOHNS, NEWFOUNDLAND.

By H. C. BURCHELL, M.Can.Soc.C.E.

The Dry Dock, which is the subject of this Paper, is situated at the Riverhead or Western end of the harbour of St. Johns.

It is built of wood and concrete. The form is illustrated on Plate IX and the following are the principal dimensions:—

Length upon top from inside of head to gate when at outer sill	600 ft.
Length upon the line of keel blocking	558 "
Width upon top at head	78 " 6 inch
" " " " body	132 " 6 "
" " " " abutments	84 " 9 "
Bottom width from inner end of abutment to angles near head	49 " 10 "
Bottom width at abutments	52 " 9 "
Depth of water over gate sill (H.W. Spring Tides)	25 "

The floor is founded on a bed of Portland cement concrete, laid on exceedingly hard cemented gravel (glacial drift) immediately overlying the bed rock. Bedded in the concrete and held down by frequent anchor straps of $2\frac{1}{2}$ in. $\times$ $\frac{1}{2}$ in. iron is a system of longitudinal pitch pine timbers 12 in. square. Immediately under the keel track, four of these are laid close together, each anchored to the concrete and all bound together by through bolts. Two on each side of the keel track timbers are one foot apart, and the remainder of the longitudinals from this to the edge of the floor are set with three feet spaces. The anchor straps are bolted alternately to opposite sides of the timbers, and are held in the concrete by a simple right angle bend.

Cross floor timbers of pitch pine 14 in. $\times$ 16 in., and 4 ft. from centre

to centre are laid on and securely fastened to the longitudinals. Their ends are boxed down to receive a stringer piece 12 in. × 14 in. which runs around the sides and head, and receives part of the thrust from the main braces.

The concrete extends beyond the floors, and is carried three feet up the sides and head behind the altars. Within the floor area it fills the spaces between cross floor timbers at their ends, and slopes thence gradually to shallow drains formed between the longitudinals, one on each side of the keel track. The entire lower system of floor timbers is completely embedded in and covered by concrete.

The working floor is of 3 in. plank, spiked to the cross timbers with ample opening left at the joints.

In order to lessen the possibility of water courses, the longitudinal timbers are omitted in the abutment, and under the gate platform and apron; but here the concrete, instead of being as at the head 2½ ft. average depth, is 6 ft. deep with anchor straps for the cross floor timbers extending to the bottom.

No indications of springs were observed during construction. It was thought best, however, in view of possible developments of either spring water or under leakage, to insert in the concrete 2 in. vertical iron tubes, 20 ft. apart, alternating on opposite sides of the keel track throughout the length of the dock. The lower ends, extending into the gravel below the concrete, were left open, and the upper ends, protruding above the concrete, were fitted with valves (light dead weights) opening upwards. There has been no flow from these tubes.

A line of sheet piling surrounds the entire structure at a distance of 26 ft. from the coping. The sides of the dock are supported by transverse frames 4 ft. apart from centre to centre, extending from the floor to the line of sheet piling, and made up as follows:—A heavy pitch pine main brace or rafter abutting at its lower end on the cross floor timber and stringer already described, and at its upper end on the coping; a cap of 12 in. square pitch pine running horizontally from coping to sheet piling; brace and cap resting on 12 in. spruce piles 5 ft. apart, all three parts of the system being bound together by a diagonal tie of pitch pine, firmly bolted to them, and acting, to use another roof term, like an ordinary collar beam.

These transverse frames are connected on top by the coping, which is built up of three heavy pieces of pitch pine, and are further stiffened laterally by the altars. The altars are of pitch pine. Two are sawn from a stick 11 in. × 14 in., by ripping obliquely, not from corner to corner, but cutting each 14 in. side 3 in. back from the corner. These

are bolted with an oblique face resting on the main braces, an 11in. side uppermost and horizontal, and a 3in. side looking towards the coping, and covering by that much the next altar above. A series of continuous steps, ascending from floor to coping with 8in. rise and 11 in. tread, is thus formed around the entire body and head of the dock, admitting of convenient access at any point.

The entrance works differ somewhat in detail of construction from the body. Six lines of transverse sheet piling on each side run from the floors to the main outer line before referred to, one at the end of the apron, two at each sill, and one at the inner end of the inner abutment. The concrete foundation is carried 5 feet beyond the floors, and the sides or walls are backed by concrete 5 feet thick at the bottom and 2 feet thick at coping. The cross floor timbers and main braces are covered by two thicknesses of 6 in. timber breaking joint. Each course is thoroughly caulked with dry pine wedges.

The transverse floor timbers in the inner abutment are 10 in. higher than the corresponding body floor timbers. The rise from the main floor is formed by six large oak timbers, rabbetted and bolted together, and backed up by heavy oak knees, running back over and framed into the main floor timbers.

There are two positions for the gate 20 feet apart. At each sill four heavy pieces of oak, rabbetted and securely fastened together, form a step or offset, that runs across the floor and up the sides, and receives the weight and thrust of the gate when in position. The top courses of 6 in. timber are rabbetted into and are flush with the sill timber. There are no grooves, and the chances of troublesome obstructions are consequently much lessened. The offsets are fitted with stout rubber gaskets, against which the gate bears and forms a water-tight joint.

The apron is constructed on a concrete foundation in similar manner to the floors of the gate platforms, the timber being covered with an extra layer or facing of concrete. The apron proper extends 21 feet beyond the outer sill with a concrete toe carried 13 feet further.

Sheet piles are of spruce fitted with dry pine tongues or keys. Bearing piles are of the same timber. All are driven to the hard gravel on which the concrete foundations of the floors rest, so that the whole structure has a perfectly uniform bearing.

The excavation of the dock basin was made after most of the piles had been driven. The material excavated was alluvium, having but a small proportion of gravel, and was found to be impervious to water; hence no more was disturbed than was necessary for the setting of main braces and ties. As the altars were put on, all existing spaces

were filled with suitable material taken from the excavation, and thoroughly rammed. Very slight indications of leakage appeared at several points in the plane, dividing the more recent from the glacial drift. This was doubtless caused by the same plane having been cut in dredging a wet slip on the South side of the dock.

The area around the dock was filled with earth carted from the neighbouring hills, and was graded level with the top of the coping timber. Cross-caps and sheet-piles are thus covered by about two feet of ground.

The cofferdam was formed by driving three parallel rows of sheet piling about 5 feet apart, each row being re-inforced by round piles and braces. The intervening spaces were filled with earth. In plan its form was three sides of a rectangle, the two parallel sides being under the piers at each side of the dock entrance, and the third connecting them just outside the toe of the apron.

The dock is fitted with sliding bilge blocks, 28 on each side, operated from the coping by endless chains. Keel blocks are placed on each cross-floor timber. They are thus 4 ft. apart from centre to centre.

Materials are sent to the working floor by means of six slides conveniently situated, three on each side of the dock.

The gate is a floating iron caisson. It is provided with a steam capstan, a 10 in. direct acting centrifugal ballast pump, and a boiler. The capstan stands on the upper or flush deck. The engines that operate it and all the other fittings are on a lower deck.

Eight pipes, or filling culverts 22 in. diameter, that pass athwart-ship through the gate, afford a means of filling the dock. They are fitted with valves controlled by hand-wheels on the lower deck.

The gate is moved into and out of position by the steam capstan and suitable warps. Raising and lowering are effected by the ballast pump and inlet valves.

The pumping installation is placed in a brick building a little to the back of the abutment on the north side. The pumps and engines were made by W. H. Allan & Co., of London, England. There are two thirty inch centrifugal pumps, each driven by an independent single engine. The discs are 5 ft. 6 in. in diameter, with curved arms similar to the Appold. The suction expands from 30 in. to 36 in. the size of the wrought iron suction pipe. The discharge expands from 30 in. to 48 in., at which size it delivers into a brick culvert 14 ft. 6 in. wide, 5 ft. 8 in. deep, and 60 ft. long. The suction is divided into two passages at the periphery of the pump, and water is drawn into the disc chamber from both sides

at the centre. Each pump is fitted with a steam ejector for priming. The engines are single, horizontal, variable cut-off, directly connected to the pump shafts having cylinders of 21 in. diameter; and 22 in. stroke.

The drainage and leakage are removed by a 10 in. Heald and Cisco centrifugal, driven by a pair of vertical engines directly connected.

The engine pit is enclosed by sheet piling. For a foundation round piles were driven 3½ ft. apart, all soft material was excavated to a depth of 2 ft. below floor level, and a quantity of loose stone thrown in. The piles were capped, and concrete laid on the loose stone was rammed round them and brought up level with the caps. A double floor of caulked 3 in. spruce was then laid, and another thickness of concrete placed on it. The pumps and engines were bedded on this foundation in concrete faced with brick. The walls of the engine house start from the same platform, the space between walls and sheet piling being filled to the surface with concrete.

There are two boilers of the marine type built of Siemens-Marten steel. They are 12 ft. 9 in. diameter and 11 ft. 6 in. long. Each hast hree furnaces 3 ft. inside diameter, 8 ft. 3 in. long, each furnace opening into a separate combustion chamber.

The contract stipulated that there should be pumping capacity sufficient to empty the dock when occupied by a 2,000 ton ship in two hours and a half. At an official trial under direction of the writer, the dock was emptied without a ship in it in two hours and twenty minutes. At every six inches fall of the water observations were taken of the time steam pressure in boilers, and speed of engines. The speed of the engines, though slightly increasing, was comparatively uniform. It so happened also that the depth of water was reduced at a uniform rate, that is to say, very nearly the same time elapsed between the observations, from which it will appear that the slip resulting from the increased depth of suction varies approximately as the contents of a layer or stratum of a given depth at varying depths in the dock.

On the south tide of the dock is a wooden freight shed 400 ft. × 40 ft., conveniently situated for a storage of cargo, either from ships in the channel dredged directly alongside or from ships in the dock.

On the opposite or north side a brick building 400 ft. × 35 ft. affords ample space for convenient office accommodation, stores and work shops. The shops are furnished with electric light plant, punch, shears, rolls, and other machinery suitable for repairs of wood and iron ships, and a stationary engine giving the necessary motive power.

Among the most prominent features in this dock are the entire absence on the working floor of discomfort or inconvenience from drain-

age; the abundance of light and ventilation for workmen, resulting from the great top width; the readiness with which shores may be adjusted, owing to the small and numerous altars; and the facilities for expeditious construction.

The materials used were the very best of their respective kinds, and the workmanship most thorough throughout.

The only casualty that occurred during construction was a slight movement of the material on the South side of the entrance works, before the frames or concrete were put in. It was promptly stopped by a system of struts to the opposite side, and gave no further trouble.

The work of construction was commenced on 28th May, 1883, and was suspended for four months during the winter of 1883-4. On the 10th Dec., 1884, the dock was formally opened, and H. M. S. "Tenedos" was successfuly docked.

From the Drawings accompanying this paper Plate IX has been prepared.

DISCUSSION.

Mr. Collingwood For nearly two years the writer has acted as Company's engineer for a similar work built by Messrs. J. E. Simpson & Co., from their own plans at Newport News, Va. The two docks are so nearly identical in dimensions and structural details that in most respects the description of one is the same as of the other. While, in general, the floors are the same, the character of the site at Newport News, required piles to be used throughout, to which the longitudinal timbers were drift-bolted. The James River at that point is about five miles wide. The shores consist mostly of fine sand and loam, so that the bottom slopes very gradually, and 25 ft. depth was not reached until about 1,600 ft. from the shore line.

The plan adopted was to build an embankment 315 ft. wide at grade, cutting down the bluff behind for the purpose, and to continue the same each side of the dock nearly to the entrance.

On the South, a timber bulkhead, 200 ft. long, served to protect the outer end of the tank, and the pump and engine house, and on the North a similar one 100 ft. long was built. Beyond these, piers 250 ft. long built on piles were extended on each side of the entrance, the heads of the piers reaching to about 1,100 ft. from the shore line, and to a depth of 9 ft. of water at M.H.W. Sheet piling was driven around the exterior row of piling, exactly as described in the paper.

The cofferdam consisted of four rows of sheeting filled with material from the excavation.

The bottom consisted of a soft surface deposit, below which, to the full depth excavated, there was a kind of marl, made up of great quantities of shells, mixed with sand, etc., from the shores, the fine material resulting from the wear of the shells giving it a greyish appearance. It would stand up vertically under water, and was exceedingly hard to dredge, but after being disturbed, made a thin, sticky mud. The cofferdam was not closed until the pit had been dredged to about its depth, and on pumping out the water there were from one to four feet of mud covering the bottom. There can be but little doubt that such material may, by suitable appliances, be most economically excavated "in the day."

The winds from the North-west and South-west have a reach of at

least ten miles, and the resulting waves caused serious breaches in the light earth banks, for which the specifications and plans (for which the speaker was not responsible) made no provision. The North side has been protected by the building of a ship-yard protected by suitable cribbing. The South side has been in great part protected by the travel of the sand along the shore, which has filled the angle so as to break the force of the waves.

The space 50 ft. above and below the piers and between them, and for 400 ft. in width, and to deep water in front of the piers, is to be dredged to 25 feet depth.

The piles are mostly of Virginia pine. Those exposed to the attacks of the teredo are of creosoted North Carolina pine, and those at the bulkheads, etc., are of oak.

The teredo is very destructive in these waters, and in one season would destroy the strength of a ten inch pile. Some of the sheeting 5 inches thick in an exposed place was entirely eaten off in one season. The creosoting, which was altogether at the discretion of the contractors, was done at Wilmington, N. C., the *wood* creosote being used; and the result, as a test of this material on a large scale, may be looked for with interest.

The centrifugal pumps for emptying the dock were carefully designed and constructed by the Southwork Iron Works, at Philadelphia. The contract requires them to empty the dock with a 400 ton vessel on the blocks in two and a half hours. A preliminary trial, without a vessel, showed that they *can* do it in about 1½ hours. The writer regrets that he cannot at present give a description of the pumps.

The dock will be publicly opened, probably on the 10th of April.

It should be stated that the dock is remarkably dry, almost too much so for the good of the timber.

The ship-yard has been started on a basis suited to present needs, and is to be enlarged as circumstances may require. With the many advantages of location, the whole enterprise bids fair to be a profitable one from the start.

Mr. R. A. Davy

Any information about the use of concrete, especially in such an important structure as this dry dock, must be of great interest to many members of our society, and one cannot but be struck with the adaptability of this particular material for the construction of this class of work, not only on account of its being monolithic, which is of very great advantage in hydraulic works, but also from the facility with which the timber work could be anchored down to it.

It would be of interest to know what kind of ingredients were used in making the concrete, also the proportions and the method of mixing and putting in place. The work having been begun with an imperishable material, it seems strange that so much wood was used in its upper portions, but perhaps the author can give some good reason for this course being pursued.

Mr. Prindle. Mr. Burchell's interesting paper is so largely descriptive, that there are some features of much interest which suggest themselves as worthy of further remark in connection with this important public work.

First, as to the design itself, with respect to the peculiar form of construction both in outline and section.

The great width on coping level, as compared with the width of floor, gives very considerable inclination to the inner face of side and head walls, and presents striking advantages in the way of furnishing light and air at the floor level of the dock.

This inclination to the vertical of the altar system, due to the great difference in width between the floor and coping levels, permits the use of low narrow altars having the rise and tread of the steps of an ordinary staircase, and thus furnishes unequalled facilities for ingress and egress of workmen, and for reaching the floor from any point of the coping. These important points of accessibility, light and ventilation are thus secured in a remarkable degree.

Minor advantages with respect to superior facilities for economical shoring, supply of materials, and access to the bottoms of vessels under repairs, etc., are not without value, and are incidental to this form of cross section.

True, the water prism is thus considerably increased, and more pumping of water is required to empty the dock than is called for in the case of masonry docks constructed with few altars of great rise and nearly vertical inner face walls, but the greater advantages of light, air and accessibility far outweigh the small amount of additional coal and time consumed in the operations of docking.

It is to be observed that the greater width of docks constructed on this general plan very largely increases the area of foundations required, and also the cube of masonry which would be necessary if constructed of such material. The consideration of this plan would, therefore, at the outset, raise the question as to the nature of the materials to be employed in its construction, and render some substitute for masonry a commercial necessity, in order to reduce the cost of construction and make the plan feasible.

The slope of the altar face walls, being about the angle of repose of earth embankments, would at once suggest the absence of any necessity for great weight or strength in the way of retaining walls to resist the thrust of earth pressure, and the absence of such retaining walls obviates in turn the necessity for the heavy and more costly foundations for the side walls, which would otherwise be required.

The selection of timber instead of granite or other masonry would appear to have been a sensible, if not indeed a necessary, choice, in order to produce a structure combining all the advantages of the design at a reasonable cost.

The volume of masonry required for a dock of this design, with its greatly extended base of foundation, would necessarily be large and costly, even though concrete be employed for backing and dressed stone used only for altars, entrance facing, floor and coping.

That timber construction, such as is here employed, would prove of sufficient strength, is attested by the numerous examples of similar docks in the States, which have been for many years in successful use, and have repeatedly received the largest steamships afloat with entire safety, even without discharging cargo; and as no mention of weakness has been made with reference to the St. Johns dock, it is presumed that none has as yet been manifested in this particular case.

So great has been the success attending these dry-docks in the States, and such is the confidence of the Government in their entire efficiency and economy, that no less than three are now in course of construction at as many Navy Yards, Brooklyn, Phildelphia and Norfolk, all of this general design, and 500 feet long on coping level.

In addition to these, another of 600 feet in length has just been completed at Newport News, Va., on the James River, thus now swelling the number of timber docks built on the Atlantic coast to 14, and, singularly enough, all designed and built by the same engineers and contractors, whose name the system bears in the States.

At first thought, the use of timber would seem unsuitable for such purposes on the score of durability, and apprehensions of this character would naturally arise in the minds of engineers (from which the writer himself was not exempt when he first entered upon the study of timber dry-docks) in considering such a construction. Experience, however, is a safe guide in this direction, and so far the question of decay of timber dry-docks has not been found to be so serious as at first imagined. It has been found that the timber most exposed to decay constitutes but a comparatively small fraction of the whole structure, and that the upper works may be allowed to greatly deteriorate without affecting the integrity of the dock itself.

Those portions which most readily decay are, fortunately, those which are most easily and cheaply replaced, and do not at all affect the foundations which may justly be considered as substantially imperishable.

In the new timber docks just referred to, precautions have been taken to protect the coping, upper altars, and the entrance works from decay and sea worms by means of creosoting.

Should all the timber in such structures which is not constantly wet be thus treated, it would seem evident that the question as to the life of timber dry-docks in respect to decay, as determined by actual experience, can only be answered by future generations.

The floating gate or caisson, for closing the dock, has doubtless its most prominent feature in the sloping stems or straight overhanging ends, whereby but little handling of water ballast is required to operate it, as but little rise is necessary to lift the gate from its seat at the sill and abutments, the latter here superseding the "grooves" of the older type of masonry docks.

The employment of timber in the construction of the entrance works here again favors the system, as it is desirable to spread the face of the entrance walls to give greater width on water line, as well as to reduce the earth pressure in rear, which would otherwise demand a considerable weight of masonry to resist as a retaining wall.

With respect to the location of the St. Johns dock, many disadvantages appear to be connected with its great distance from a base of supplies, as well as inconvenience of access by reason of ice and fogs on a forbidding coast.

The country and vicinity itself contributed but little else than ordinary labor, and a meagre quota of materials for construction, so that practically, all materials, machinery and plant had to be imported from a considerable distance, in all sorts of weather, on a dangerous coast.

A consideration of the difficulties encountered due to such a location only serves to emphasize the facts, as to the remarkably short time actually required for the execution of a work of this magnitude.

Begun in May, 1883, and completed in December, 1884, with four months suspension of work during the intervening winter, the actual time consumed was less than fourteen and one-half months, which is regarded as a noteworthy achievement. While much is doubtless justly due to the large experience and well-known energy of the contracting engineers themselves, the principal reason is to be found in the specially favorable constructive features peculiar to the design itself, which furnishes such exceptional facilities for rapid construction, as compared with masonry docks of usual type.

Contrasted with the yet unfinished United States Government graving dock at Mare Island Navy Yard, California, of granite and concrete masonry, which has been more than a dozen years under construction, at a cost approaching $3,000,000, the comparison is very significant. True, work on the latter structure has been much interrupted and delayed, and its cost greatly increased, through repeated failures of Congress to furnish money in regular and adequate amounts as the work progressed, but the climate there is most favorable for prosecuting engineering works, particularly masonry constructions, without interruption throughout the year.

The three new timber docks, before referred to as now under construction, will probably all be in use before the final completion of this granite dock at Mare Island.

Some years ago the writer had occasion to remark, after careful study of this system of dry dock construction, that in his judgment the last stone graving dock had been projected in this country. And now he is gratified to note that the old-time conservatism has given way to more modern ideas and progress in the adoption of this system by the Government, in the official advocacy of which he was the pioneer.

It would be interesting to learn what has been the effect of ice and the winter climate on the St. Johns dock during the five winters now succeeding its completion, as also upon the new granite dock at Quebec, of more recent construction.

The granite docks at Boston and Brooklyn Navy Yards began to yield to the effects of ice and frost after a few years exposure, and notably so at Brooklyn, where the masonry finally became so much destroyed as to render the dock inoperative, and necessitated the reconstruction of the entrance works, relaying of the stairways, timber slides, etc.

Mr. Burchell, in his very interesting description of the wooden Dry Dock, at St. Johns, Newfoundland, claims for it certain advantages, due principally to the character of the altars, and the correspondingly great width of the dock at coping level; but the advantages claimed appear to the writer to be doubtful ones, for the following reasons. Mr. Boswell

The change in ocean going vessels, from the wooden sailing vessel to the iron steamship, has caused a corresponding change in the character of the repairs generally required to be executed in a dry dock. The materials necessary for the repairs to wooden vessels consisted essentially of square timber, planks and knees; and these could be readily slid down the timber slides to the bottom of the dock, where they are

fitted and placed in position. This was before the days of electric and lucigen lights, and it was consequently advantageous to provide for sunlight by increasing the coping width. With steamships the case is however different, the materials required for repairs consisting, for the most part, of heavy masses of iron, plates, and parts of machinery. The fitting and preparing of the material is completed before it is sent down to the ship, the piece having merely to be put in place on arrival. In the case of a plate, the rivetting necessary for securing it in position has partially to be done from the inside of the vessel, and would require artificial light in any case. Again, these heavy pieces of iron are more readily handled by a steam crane than in any other manner. A steam crane travelling along the coping of the dock can deposit the pieces of machinery, plates, etc., just where required. To avoid an excessive length of boom in the crane, the more nearly vertical the sides of the dock are the better, while with fewer altars and more nearly vertical sides to the dock, the shores also become shorter, which is an undoubted advantage. Some of the older stone docks were constructed with a cross section very similar to the wooden dock at St. Johns, but in the more recent ones, the number of altars has been diminished, so as to reduce the width at the coping.

A dry floor is placed by Mr. Burchell among the prominent features of the St. Johns Dock, but this should be and is a prominent feature of all properly constructed docks, whether with wooden or stone floors.

In a report on the wooden dock at St. Johns, by Mr. Keating, the City Engineer, Halifax, he gives the quantity of water discharged by the drainage pump due to leakage, and surface drainage at 965 gallons per minute; and this large volume of water must pass under the floor, and keep a portion of the timbers damp. That the exhalations given off from damp and decaying timbers, under the heat of a mid-day sun, can be healthful for the workmen is, Mr. Boswell considers, a matter open to considerable doubt.

Prof. Bovey. According to the reports of Mr. E. H. Keating and others, it appears the advantages claimed for wooden docks over others are—that they are drier, more comfortable and wholesome, cooler in summer and warmer in winter, and more easily freed from ice; while specially great advantages are that the altars are low and narrow, affording greater facilities for manipulation, that the form of the altars renders it unnecessary to cut the shores, that the actual repairs on a wooden dock are less than on a stone dock, and that the interest saved on first cost of construction is quite sufficient to cover all the extra cost, if there should be any, of repairs.

The speaker does not know exactly how these conclusions have been arrived at, but probably they have been reached by comparing an efficient timber dock with masonry docks of an inferior character. He feels sure that with a proper foundation it is possible to render a stone dock quite as dry and free from moisture as a timber dock, although the contrary is maintained by timber dock promoters.

In regard to the form of wooden altars, being more suitable for the repairs required on ships, it was quite possible to dress stone altars in precisely the same form if necessary, but he thought Mr. Boswell had given good reasons why the extra width of the timber dock was not suitable when steamship repairs were required.

In the matter of cost, he fancies that the item would have to be gone into very carefully before any safe comparison could be arrived at, as to the superiority of any one class of dock over another.

As to durability, timber under fresh water is practically imperishable, but when exposed to salt water it is liable, unless protected, to suffer from the attacks of the teredo and other sea worms. Experience on the Mersey Docks, Liverpool, has proved that one of the greatest safe-guards against the teredo in any class of timber work is creosoting, which has met with the most marked success.

The upper portion of a timber dock must soon decay, and as it would require replacing every few years, it is a question if the cost of these renewals capitalized would not be sufficient to build a stone dock. He thought that anyone who had seen the masonry docks in Liverpool could not fail to be impressed with the idea that it was better to have a stone dock if possible.

Doubtless when kept in as good state of repair, timber docks are quite as efficient as stone docks.

Mr. P. A. Peterson said that the author's paper, although instructive in many points, was of too general a character, and did not enter enough into detail in regard to the plan and method of construction, while the details given as to pumps and buildings might have been less discursive. Mr. Peterson.

An important point, not stated, was whether there was any trouble caused by the teredo, perhaps none was experienced, but at any rate the matter should have been mentioned in the paper.

Information should also have been given as to the composition of the concrete used, the brand of cement, and also the details of the framing would have been interesting and valuable.

Mr. Walbank. W. McL. Walbank agreed with the remarks of the previous speaker, that the subject under discussion might have received fuller treatment at the hands of the author. The situation of the dock was at the mouth of Waterford Bridge river or upper end of the harbour at St. Johns. This small river, in Spring, sent down a considerable stream of water although there was very little in the Summer. The geographical situation in this case was not shown, and nothing was said as to how the water passed away clear of the dock, or of the difficulties encountered in dealing with it. There was also a bridge on the shore end, built of ordinary crib work, filled in with stone, the centre being left open for the water of the river to pass through. He did not know whether the dock was built on the North or South side of the harbour.

All the wharves in St. Johns were of wood. He could not say whether they were attacked by the teredo, but he believed the mussels stuck all round the piles.

There was nothing said about the cost of the dock, nor had any information been given about the rise and fall of tides and as to what extent they affected the dock.

Mr. Devereux The following remarks must be accepted as the results of practical working experience, rather than as touching upon the scientific construction of any kind of graving dock. In the writer's opinion the design of the dock is excellent, especially the arrangement of the engines, centrifugals, discharge culverts, and entrance piers—and is no doubt all that could be desired for facilitating the docking and repairing of ships, if the structure is watertight, and the dock can be kept dry at a small expenditure of fuel.

On this latter point the whole economy of a dock, as a paying institution, rests. What with the wear and tear of the machinery, added to the cost of fuel and other stores, and the continually increasing leakage eroding away the foundations of the structure, a dock that leaks much will always be a continual source of trouble and expense. On this point the writer wishes to be clearly understood, because from his own experience he does not consider concrete impervious to water under great pressure. During the construction of the dock precautions seem to have been taken to guard against leakage from every direction—especially at the bottom; but whether this proved effectual after the cofferdam was removed is not stated.

In some docks differently constructed from this one, the floor has been lifted by the pressure of water underneath; but, of course, such a case must depend much upon the nature of the surrounding formations and

the stratum on which the floor of the dock rests. It was only last year that the construction of a dock at Portland, Oregon, similar to the one under discussion, had to be abandoned on account of this water pressure. In the province of British Columbia drift-gravel, hardpan or till overlying rock, is a good bed to build upon, and is usually very free from springs and leakage crevices.

There remains another very important matter to be considered in the construction of the dock in question:—Is it advisable to build docks of such large dimensions of wood and concrete only?

In the writer's opinion it is not desirable to do so, as it is to be supposed that it is built for the accommodation of large vessels only. A smaller and much cheaper one would answer all purposes for small craft, and then a wooden structure would be strong enough, and last for many years if the timber were well covered with concrete, and kept continually wet.

To come now to the practical working of a large dock, and taking for example the docking of one of the Atlantic liners—say of 6,000 tons. If this vessel's keel is straight, and she preserves a perfectly uniform bearing on the keel blocks, there will be no difficulty experienced with the docking of the ship, but as a rule these vessels, after having been in use for a while, do not preserve their original lines, but sag down in the middle, or where the greatest inside weight is; and when the vessel is docked in this condition, it is obvious what the effect will be upon the keel blocks and the floor of the dock. Quite recently, there was a vessel of this description docked at Esquimalt, and the owners thought it necessary to have the ship raised higher than the usual keel blocks admitted. For this purpose the best Douglas fir that could be found in this Province was used. Though warned as to the result, they thought they would risk the consequences, and when the ship was landed on the structure built of 12in. × 12in., she crushed it down like so much match wood. Of course pitch pine bears a greater crushing strain than our fir, but this is merely mentioned as an example of what might be expected if the above 6,000 ton ship had been ashore, and possibly hogged, or if large portions of her keel had been removed in several places, the ship being at the same time probably loaded, and two or three compartments full of water. What then would the effect be upon the bottom of a wooden dock of such great length with the keel of the vessel resting upon the blocks in two or three short spaces only, and not continuously along the whole length of the ship? Take the case of one of Her Majesty's ships of the 1st class, say of 11,000 tons, with her coal, stores and battery all on board. She must

be docked at once, for she is leaking, and part of her keel gone (a case likely to occur within the "next few days at this dock 'Esquimalt,' "for one of Her Majesty's ironclads has been ashore, and part of her "keel gone or said to be gone, but not leaking"); however, she must be docked in that condition. How would it fare with a wooden structure in such a case? No doubt it would suffer badly, and the Captain of any such vessel would be loath to put his ship in a wooden dock, unless it were to save her from sinking.

There is a wooden dock 450 feet long at San Francisco, similar to the one under discussion, but no ironclad has been in it up to date, and it is a well-known fact that the floor of the dock has suffered considerably under much less weights than above described. Moreover, it is not very many years since one of H. M. Ships on this station got ashore and had to go to San Francisco to be docked, where she went on the United States Pontoon Dock at Mare Island Navy yard—broke it down, ruined the ship, cost the Imperial Government $150,000 to repair the dock, and after all, when the ship went home, she was condemned, and never again went into commission.

Mr. H.F.Perley The builders of the dry dock at St. Johns, Newfoundland, Messrs. Simpson & Co., of New York, claim that by their system of constructing in wood, the cost of such structures is reduced to a minimum, and therefore it should be adopted in preference to constructing in stone.

Mr. Burchell does not give the cost of the dock at St. Johns, neither is it given in an "Official report of a Board of Inspectors, ordered by the Secretary of the U.S. Navy" to examine that dock, but the sum of $556,000 appears in a report submitted by Mr. E. H. Keating, City Engineer of Halifax, N.S., to the Mayor of that city, on an inspection he made in December, 1884.

Taking the length as stated by Messrs. Burchell and Keating, the cost per lineal foot may be placed at $1,000, and this without any allowance for land damages, or customs dues on materials, machinery, etc., which were admitted into the colony free of duty.

In January last the U.S. Government called for tenders for the construction at League Island Navy Yard, of a timber dry dock 500 feet in length, 130 feet in width at the top, and 50 feet at the bottom, with a width of 80 feet at the entrance, and a depth of 25½ feet on the sill, with caisson, culverts, pumping plant, etc., complete, and the only offer received was from the Messrs. Simpsom, whose price was $548,700 for the dock complete, and $975 per lineal foot for any length over 500 feet.

The (stone) dock proper at Esquimalt, B.C., cost about $1,500 per lineal foot, which included land, coffer-dam, unwatering, caisson, valves, pumping machinery, buildings, etc., and when called upon to estimate the cost of extending that dock a length of 100 feet, the writer placed it at $1,000 per foot, that being the actual cost of constructing *one foot* of the body of that dock.

It is extremely questionable whether a wooden dock at a cost of $975 per foot can claim any character for cheapness when compared with the dock at Esquimalt, where labor and materials are higher than on the Atlantic coast; and certainly on the score of permanency, maintenance and repairs, the stone structure has the pre-eminence, and thus the claim for cheapness falls to the ground.

On this point it is well to quote from the report by Mr. Keating, referred to herein. "It is claimed for wooden docks that their comparative cheapness should outweigh all other considerations. The American patentee claims that 'the original cost is less than one-tenth that required for a permanent stone dock,' and if this, or even a much higher value had been fixed as their true worth, there would be no need for further argument in their favor. An examination into the facts, however, shows that in some cases at least, their actual cost has not fallen short of a fair price for a similar stone structure in a favourable locality. The two wooden docks at Brooklyn are reported as having cost as they stand to-day $1,283,356 (exclusive of interest), or say $640,000 each, although they are both operated by the same set of pumps; and in the case of St Johns, if the value of the land and the remitted duties be added, it will be found that the actual cost of the dock at that port has been about the same sum. A carefully designed permanent stone dock with all its appendages, under similar favorable circumstances, and suitable building materials within a reasonable distance, would not in my judgment prove any more expensive."

Thursday 9th May,

P. A. PETERSON, Vice-President, in the Chair.

Paper No. 31.

THE ESQUIMALT GRAVING DOCK WORKS, BRITISH COLUMBIA.

By W. BENNETT, M.CAN.SOC.C.E.

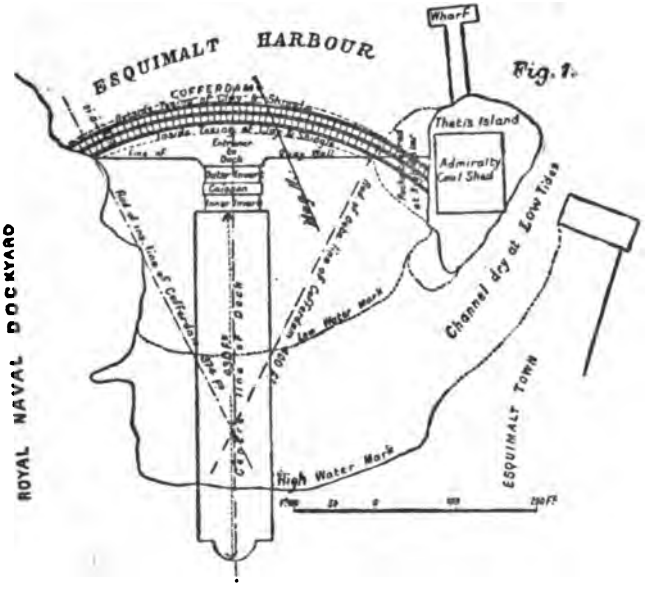
These works, which were fully illustrated in "Engineering" of the 20th and 27th of July, 1888, were originally commenced by the Government of British Columbia, and have been completed at the cost of the Dominion of Canada, the Imperial Government contributing £50,000 thereto, in consideration of which, any of H.M. ships have priority of entry and free dockage for 15 years, on payment of working expenses only. The works were designed by Mr. Kinipple, the senior member of the late firm of Kinipple & Morris, Engineers in Chief for the whole of the works.

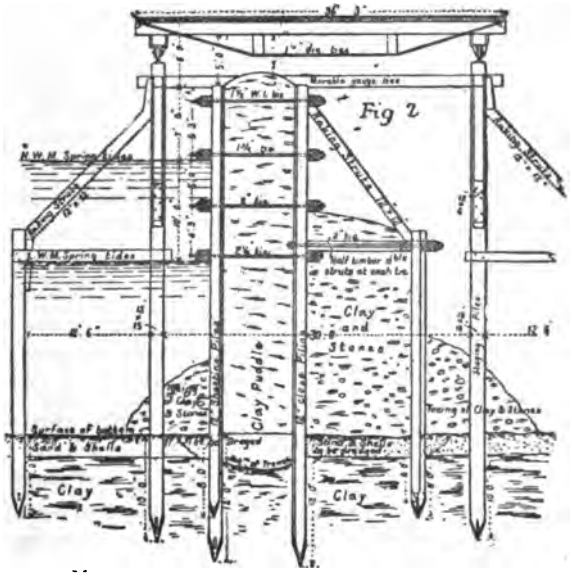
The outer or Cofferdam works (Figs 1 and 2, p. 221), were commenced in September, 1876, and the inner or Dock works some four years later. The Earl of Dufferin, then Governor General of Canada, was present when the first pile of the dam was driven. The Dock was opened on 20th July, 1887, H.M.S. "Cormorant" being the first to enter, and followed, when her repairs were completed, by H.M.S. "Caroline."

The progress of the outer works was to a certain extent hindered by the fact that at Esquimalt the range of tide, which was supposed to be about 10 feet, is very uncertain, the tide remaining frequently at almost H.W. level for days together, which thus prevented the wales and struts of the dam being placed in their respective positions. The original drawings had therefore to be somewhat modified in order to prevent further delays in the completion of this portion of the work.

In January, 1876, the contract for the Cofferdam was given to Messrs. Reed Brothers, of Tokenhouse Yard, London, by the British Columbian Government, for the sum of £12,311. Owing, however, to the non-fulfilment of their contract in the specified and extended time, the Government, in June, 1879, after the contractors had ceased work altogether, took possession of the Cofferdam works, and completed

them in the following October, under the superintendence of their Resident Engineer.





When the water was pumped out from the area on which the Graving Dock was to be constructed, the dam was found to be perfectly tight in every respect, although for fully one-third of its total length, of upwards of 500 feet, at the shore ends, the sheeting piles had to be planted on a very uneven foundation of rock, overlaid with sand, shells, and boulders, all of which, of course, had to be removed. Some of the holes for the rock pile shoes were drilled in 25 feet of water. The dam did not show the slightest strain when the full pressure, due to a head of nearly 30 feet, was brought against it, and remained intact until it was removed on the completion of the Dock in 1887. Although the dam was not removed for 7 years after its completion, no pumping whatever was required during that time beyond that which was due to percolation through the strata, or to rainfall.

The three sluices through the Cofferdam were not constructed as shown on Figs. 5, 7, and 8, so much on account of the tidal difficulties already referred to as for the avoidance of leakage, and in lieu thereof one sluice, equal in capacity to the three proposed, was built in the channel way at the back of Thetis Island (Fig. 1), and by its means the Dock was flooded at the testing of the caisson against the meeting faces.

The greater portion of the Portland cement used in the construction of the Dock was supplied by Messrs. Gibbs & Co., of Gray's Essex, and the remainder by Messrs. Robins & Co., and other well known English makers.

In June, 1875, tenders were ordered to be obtained for the Dock pumping machinery, and Messrs. James Watt & Co., of Soho, Birmingham, secured the work at the contract price of £6300. This contract included the boilers, engines, caisson hauling gear, sluices, pumps, &c. The boilers (3 in number, one spare) are of the cylindrical and multitubular type, each 15 feet long, and 6½ feet in diameter, having 2 flues 4 feet 6 inches long, 2 feet 3 inches in diameter, a large combustion chamber, and 120 tubes 2½ inches in diameter, 5 feet in length. (Fig. 27). The boilers were tested to 120 lbs. per square inch, the working pressure being estimated at 60 lbs. The main pumping engines are capable of raising 907,000 cubic feet of water in 6 hours, with an extreme lift of 35 feet, and a mean lift of 17 feet 6 inches. These engines are of the low pressure condensing horizontal description. The cylinders, 2 in number, are 27½ inches in diameter, with a stroke of 4 feet. The main pumps are 4 feet in diameter, and 5 feet stroke, the working barrels (Fig. 24) of which are lined with brass; the pump buckets are also of brass, with india-rubber valves, and designed to discharge from 15,000

to 18,000 gallons per minute. The auxiliary engine is of the vertical direct acting description, having a cylinder 14 inches diameter, and a 12 inch stroke. This engine is used both for working the auxiliary pumps and the caisson hauling gear. The auxiliary or drainage pumps, 2 in number, 10 inches in diameter, with a 2½ feet stroke, are jointly capable of raising 600 to 800 gallons per minute, 50 feet high, (Fig. 26).

The whole of this machinery was delivered at Esquimalt in 1876, and stored, with the exception of the auxiliary pump, which was used to pump out the area behind the Cofferdam, and also to keep down the surface drainage during the whole period that the works were under construction; thus the necessity of obtaining special pumps for this purpose was obviated.

On the 5th of September, 1879, tenders were advertised for the main works, and Messrs. F. B. McNamee & Co., Montreal, were the successful contractors.

The works, however, were not commenced before the 13th of September, 1880; but progress was slow, and in April, 1882, the contractors stopped work, and consequently, in June, 1882, possession of the works was taken by the Government of British Columbia. The works were carried on for the following 12 months by day labor, and again under the direction of their Resident Engineer. On the 24th of August, 1883, the works were handed over by the Government of British Columbia to the Dominion Government, under the terms of the Settlement Bill, one of the terms of which Act provided for the repayment of all sums expended on Dock account by the Federal to the Provincial Government.

The Dominion Government thereupon advertised for tenders for completion of the works, but it was not until November, 1884, that the tender of the well-known firm of Messrs. Larkin, Connolly & Co., of Quebec, was accepted, and they afterwards prosecuted the works to completion with great energy and ability.

The Dock is 450 feet in length (Fig. 9) from the inner face of the caisson, when in its ordinary berth, to the base of the circular head, and has a width at the entrance of 65 feet. (Fig. 10.)

The walls of the Dock are parallel for the entire length, and the width across the floor is 41 feet. The top inside width of the Dock at coping level is 90 feet, and the depth on sill at ordinary H.W. is 26½ feet. Occasionally, however, the tide rises from 2½ to 3½ feet higher.

The excavation for the Dock, which was commenced in 1880, was mostly in sand and shells for a depth of about 3 feet over the entire area of Thetis-Cove. Below this level very stiff brown and blue clay

was encountered (with occasional boulders imbedded), with the exception of an out-cropping of rock, which occurred about half way up the Dock, continuing to the end, and under the caisson chamber and engine house foundations.

The whole of the foundations of the entrance works are of cellular brickwork, laid in 3 to 1 Portland cement compo, and the pockets filled in with concrete.

The walls and Dock entrance are 7 to 1 rubble concrete, faced with sandstone in 2 feet courses. The sandstone facing of the Dock, according to the contract drawing, was in 1 foot courses; but as good stone was easily obtainable of large size in the district, it was ultimately decided to adopt 2 feet courses. The sandstone was obtained from Salt Spring or Admiralty Island, and the granite from Nelson Island, respectively distant from Esquimalt, 50 and 100 miles. A skin of 9 inches in thickness of 5 to 1 Portland cement fine concrete was introduced into the bottom of the whole of the foundations, against the backs of all the walls, and also behind the brickwork and stone facing work, and generally throughout the works.

The Dock side-walls are built vertical, the upper portions being carried by rubble concrete arches. Under the bottom of the Dock there are 6 arterial box drains, laid in 5 to 1 Portland cement porous concrete, which are connected with the rubble drains running behind the walls in each arched recess, the whole of which discharge into the drainage pump well.

The inverts are 112 feet radius, the outer being 15 feet wide, and the inner 20 feet, both of which are faced with sandstone with a hearting of brickwork and 7 to 1 concrete, (Figs. 10, 11). The caisson berth meeting faces and quoins of the invert are of granite, which are fine-axe dressed for 12 inches in width, and have a projection of $\frac{3}{4}$ of an inch. (Fig. 10).

The invert at the bottom of the caisson chamber is of brickwork set in 3 to 1 Portland cement compo, and founded on 7 to 1 concrete, and the walls of the chamber are of hammer-dressed sandstone, in 2 feet courses, with 5 arched recesses on each side. The chamber is provided with stop quoins (Figs. 13 to 17) at its entrance, and by means of balks of timber inserted therein, can be converted into a dock for painting or repairing the caisson.

The cast-iron boxes carrying the rollers on which the caisson travels are set in brickwork on the bottom of the chamber and berth. At each end of the caisson chamber pathway there is a scouring culvert, which can be used, when desired, to clear the roller pathway of any mud that may accumulate, (Fig. 10).

The dock is provided with four timber slides and stairs, of finely dressed masonry, two at the head and two at the stern. There are also twelve cedar double fenders, with ladders in them of 4 feet in width, six patent hand power capstans, and the necessary mooring posts, a powder magazine, all necessary lavatories, &c., three hydrants on each side of the dock, with a first-rate water supply. Outside the entrance to the dock are two wrought-iron buoys attached to screw moorings by a 2½ inch stud cable, for the purpose of facilitating the docking and undocking of vessels. The works are now lit up at night by electricity. The engine and boiler house and chimney shaft are faced with hammer-dressed ashlar, backed with brickwork in Portland cement. The chimney shaft is 90 feet 9 inches above coping level; and it was found necessary to go to 45 feet below coping for foundation for the same.

The paving at the centre portion of the dock bottom, for a width of 10 feet, consists of two courses of stone 2 feet in depth and 1 foot 9 inches in width, and filled in between with five courses of 18 inches in depth, and the remaining portion of the dock bottom is paved with twenty courses of stone 2 feet in depth by 18 inches in width, the whole being laid in Portland cement compo.

The discharge pipe from the auxiliary drainage pump is carried through the quays, and across the caisson chamber immediately under the surface of the quays, and down the face of the harbour quay wall.

There are also two culvert mouths, 4 feet in diameter, in the faces of the harbour or quay walls. The one on the west side is the discharge from the main pumps, and the other for scouring the caisson berth at its eastern end.

One of Mr. Kinipple's patented Travelling and Folding Bridge Caissons was constructed and erected for this dock, by the Dominion Bridge Works Co., at Lachine, Quebec, and transported in pieces by the Canadian Pacific Railway to Esquimalt. The caisson illustrated is provided with keels, which travel on two lines of rollers placed on the bottom of the chamber and caisson recess, (Fig. 19).

The Folding Bridge on the top of the caisson is supported by levers having adjustable tail weights, which together form a parallel motion. The raising and lowering of the platform is effected by rollers on the nose of the platform against curved plates placed in the abutment.

The caisson, which is hauled by steam power, may be drawn in or out of its recess in less than five minutes, and in any weather. It is divided into two parts, the lower being an air-tight chamber of sufficient capacity to reduce the weight of the caisson on the rollers to a minimum,

and the upper a flotation chamber, from which the water is pumped out by means of a Pulsometer whenever it is necessary to float the caisson out of its berth. Abrasion of the meeting faces of the caisson and granite sills and stop quoins is prevented by the keels having "swells" in them, as illustrated (Fig. 23), which ensures a clearance between all the meeting faces, when the caisson is being hauled into or out of its recess.

The sides of the caisson are vertical, but are bevelled horizontally, the inner face being of less width than the outer, in order that by moving the caisson a short distance back into its chamber, and allowing the caisson to float high enough to clear the invert or sill, it may be turned round and floated out, when necessary, for repairs, &c. The caisson, when afloat, can also be berthed against the outside meeting face of the outer invert, and by this means the available length for dockage would be increased by 31 feet, and the length of the dock from the inner face of the caisson to the base of the circular head would then be 481 feet.

By constructing the caisson as above described, the usual battered sides are dispensed with, and a saving of about 10 feet in width of the entrance is thereby effected.

The caisson is constructed of a series of horizontal and vertical angle and T irons, with cross diagonal bracing 4 feet 6 inches apart. The outside plating varies from $\frac{1}{2}$ inch to $\frac{1}{4}$ inch in thickness. A teak meeting face or rubbing piece 1 foot 3 inches wide is attached to the inside and outside faces of the caisson, following the vertical sides and radius of the invert.

The displacement of this caisson is 530 tons, and its entire weight equals 294 tons, made up as follows:—Cast iron, 63 tons; brass, 4 tons; wrought iron, 199 tons; teak face and other iron work, 28 tons; the weight of the concrete ballast, over 180 tons.

The width of the rising and falling platform is 10 feet, the height of the caisson from the inner side of the keels to the coping level is 34 feet 10 inches, the length 67 feet 2 inches on the inner or dock side, and 71 feet 2 inches on the outer or harbor side. The keel blocks are of cast iron, in three pieces, wedge shaped, the lower piece is checked into the stone paving, and each block is provided with a hard wood cap and a rubbing piece on top.

The dockage rates are at present as follows:—

Gross Tonnage of Vessel.	For the first day of docking.	For each follow'g day, including the undocking day.
For all vessels up to 1000 tons . .	$400 00	10 cents per ton.
From 1000 to 2000 " . .	500 00	8 " "
" 2000 to 3000 " . .	600 00	6 " "
" 3000 to 6000 " . .	700 00	5 " "

It may be of some interest to mention that the above rates are less than those at Yokohama, Japan, or than those at San Francisco, U.S.A., (which are from 100 to 300 per cent. higher), should a vessel occupy the dock from 7 to 10 days.

The Royal Naval Dockyard adjoins the Graving Dock property, and to the westward thereof, thereby affording great facilities for repairs to any of Her Majesty's ships.

The total cost of the Graving Dock Works, inclusive of the site, the cofferdam works, as well as the engine and boiler houses, pumping machinery, and caisson, amounted to about £180,000.

Mr. William Bennett, M. Inst. C.E., M.Can.Soc.C.E., was the Resident Engineer from 1875, until the completion of the works in 1887, and Mr. Francis O'Reilly was for two years his assistant.

From the Drawings accompanying this paper, Plates X and XI have been prepared.

DISCUSSION.

[Mr. Perley. The construction of the graving dock at Esquimalt was undertaken by the Government of British Columbia, in accordance with plans prepared by Messrs. Kinipple & Morris, of London, England.

In 1876, the coffer-dam was commenced; but owing to failure on the part of the contractor, the provincial authorities took possession, and completed it in 1879.

During 1876, the pumping machinery arrived in Esquimalt, and remained in store until 1886, when it was eventually put in place.

In 1879-80, a contract was entered into with Messrs. F. B. McNamee of Montreal for the construction of the dock proper, it being stipulated that the cement (Portland) should be supplied by the Government. After arrival in British Columbia, Messrs. McNamee & Co. associated themselves with some local contractors, but this did not tend to facilitate the progress of the work, which was slow and delayed for the want of cement, the result being that in April, 1882, operations ceased entirely. Possession of the works was taken by the provincial authorities, who carried them on by day labour until August, 1883, when they again stopped, and passed into the hands of the Dominion Government, and under the direct control of the Minister of Public Works.

Steps were at once taken to complete the dock. The works were placed under the direct charge and control of the writer as chief engineer, the services of Messrs. Kinipple & Morris were dispensed with, and they had not anything to do with the actual construction and completion of the dock; Mr. Wm. Bennett being retained as resident engineer.

No change was made in the plans, but the original specification was revised, and the first set of tenders having been rejected, a second set was obtained, and the work was let in 1884 to Messrs. Larkin, Connolly & Co., who were at that time proceeding with the construction of the graving dock at Levis, Quebec. Under their management the dock was brought to completion in 1887.

As designed by Messrs. Kinipple & Morris, the dock was only 380 feet in length on the floor, the plans providing for an extension at a future date, the works in connection with which occupied a length of 50 feet. These works were abandoned by the writer as useless, and a

circular head, as at Quebec, was built, thus extending the floor to a length of 430 feet, making the dock proper available for vessels up to that length, and by "blocking up" on the keel blocks and the inner invert, a vessel not exceeding 445 feet in length over all could be docked.

During the progress of the work a change was made by the writer in the dimensions of the ashlar in the dock-walls, and courses of two feet in thickness instead of one foot, as per specification, were adopted, much to the benefit of the work.

The plans provided for the use of brick under and in connection with the inverts and outer walls and in the pump-wells and culverts. Experience has shown that this was a mistake, as much trouble has been had in the wells, the bricks not being water-tight, or hard and solid enough to stand the strains of the pumps when in motion.

The pumps which had been furnished were not found to be sufficient for the work they were supposed to do, and a 12 inch centrifugal pump had to be provided to ensure the unwatering of the dock within a reasonable time, and to be available in the event of an accident to the main pumps.

With respect to these pumps it may be of interest to state that during the past winter it was found that owing to galvanic action, caused by the sea-water, the iron pump rods, where they joined with the brass plungers, were corroded or eaten away to such an extent, that immediate steps had to be taken to prevent a break down; and changes are being made, which will, it is hoped, prevent trouble in the future.

The dock is in good working order, and may be said to be constantly employed, as there is not a dock on the Pacific coast nearer than San Francisco, or across the ocean at Yokohama, Japan.

Mr. Bennett is in error in stating the cost of the dock to be about £180,000, say $800,000, as payments were made to the Provincial Government for work done under the McNamee contract, and by day labor, together with a bulk sum payment of $250,000, as well as sundry payments in settlement of claims arising out of engagements made prior to 1883, so that the ultimate cost may be placed at $1,000,000.

In connection with this dock the writer notes that Mr. Bennett has not made any reference to Sir Jos. W. Trutch, K.C.M.G., M. Can. Soc. C.E., who, as agent of the Dominion of Canada, exercised on behalf of the Minister of Public Works, and under the terms of the contract with Messrs. Larkin & Co., direct control over the works during their progress, and up to their completion and acceptance, and it is but just that due recognition should be made of the services which he, a civil engineer by profession, so ably rendered and so freely gave.

Mr. Henshaw. The bottom (stiff blue clay, or rock) on which the structure rests, was a very favorable one for coffer-damming, though by no means free from difficulties. It would seem that a much less massive dam would, if not necessary for protection against storms, have been sufficient, yet it certainly is no fault that every precaution was taken where the safety of so important a work was concerned.

The speaker assumes that both ends of the dock rest on solid rock, and the middle on stiff clay. The strain on the walls would therefore be similar to that of a yielding truss and settlement in the wall after being finished would result in a crack at the bottom narrowing gradually to nothing as it rose. The only evidence of its existence would be a depression of the level at the top and leakage; but as nothing is said of the former, and the latter is stated not to exist, we may assume that little, if any, settlement took place after the completion of the wall.

As the speaker has had on more than one occasion to deal with transition from rock to other material, and has seen one serious rent in a heavy wall, built partly on rock and partly on a solid bank of natural gravel, it would be interesting to him to know the mode of building, which was adopted, in the progress of works.

He imagines that the lightness of concrete compared with stone, together with the saving induced by its arched construction, would assist in reducing settlement, but that a still greater advantage would be obtained by building the portion over the clay first up to high water before connecting with the rock.

Mr. E. Mohun. It is generally admitted that, from an engineering point of view, the dock, except as regards its size, has been ably designed and ably executed.

The time, from the date of the first contract to that of the completion of the works, about 11½ years, certainly appears to be in excess of that which might be considered reasonable. The various delays incurred did not, however, arise from any failures in the work, but, as pointed out by the author, from financial and other difficulties beyond the control of the engineer.

The great fault in the dock lies in its size,—450 feet, or with the caisson at the outer invert, 481 feet long, and 65 feet wide.

Since the completion of the Canadian Pacific Ry. has opened a new route to Asiatic and Australasian trade, the inference would appear natural, if we wish to control that trade, that the Pacific steamship service should be no whit inferior to that of the best Atlantic lines. It may be assumed that the builders of the fast steamers, crossing the

latter ocean, are proceeding on a correct principle in increasing the size of their vessels within certain limits, which limits are yet apparently unknown.

The "City of Rome," built in 1881, six years before the dock was completed, and, indeed, at a time when work on the dock itself may be said to have only just commenced, is 546 feet long with 52 feet beam, or 65 feet longer than the extreme length of the dock, and only 13 feet narrower than its width. Surely this dock should have been of sufficient size to accommodate, not only the largest ships afloat, but also to allow for a possible increase of size.

If, as will in all probability be the case, the next year or two sees Pacific steamships of equal size and power to those now crossing the Atlantic, it may become cause for regret that they are unable to obtain dockage in British Territory on the Pacific coast, no matter how urgent their requirements may be. If the writer remembers correctly, the desirability of extending the dock was repeatedly pressed upon the Governments while the work was under construction.

Mr. Bennett has furnished us with an admirable description of the completed works, and apparently did not encounter any engineering difficulties worthy of special mention.

There is a subject, however, which has evoked no little interest at previous meetings, and on which the author must possess a fund of useful information, namely concrete. There is no doubt that if Mr. Bennett would supplement his paper with some of the results of his experience, his remarks would be highly appreciated.

It would appear from the bills of quantities that there were required in the construction :—

30,639 cubic yards of concrete.
6,556 " " brickwork.
109,887 cubic feet of masonry.

Mr. Summerfield.

The fact that the dock is in almost continual use, and that in some instances vessels are awaiting their turn, is ample proof that it is a success. As with all other works of a public character, there has been the usual amount of criticism, but Mr. Bennett has brought the work to a successful issue, and is therefore entitled to much of the merit attached to the undertaking.

Mr. Whited.

The folding bridge is a very ingenious arrangement. It enables the space in which the caisson floats to be bridged over, so that when the caisson is drawn back the bridge is under it, and when the dock is

closed the floor of the bridge comes up level with the bridge over the opening, and therefore there is nothing to impede the traffic.

Mr. Irwin. Is there not some mistake in the statement made by the author in regard to the caisson? If the lower part of the caisson were an air-tight chamber and the upper part half full of water, it would seem as if it would not take much to upset it on starting to float it out.

Mr. Whited. With reference to Mr. Irwin's remarks, the object of the air-tight chamber is to reduce the weight on the rollers to a minimum, the displacement of the air-tight chamber being about equal to the total weight of the caisson and concrete ballast. The upper part is filled with water only when the caisson is in its place, it is then prevented from tipping over by the masonry. At that time the valves which drain the upper part of the caisson are left open, and the water is at the same level inside as outside. But when the caisson is to be floated out of its berth these valves are closed and the water is pumped out.

Mr. T. B. Brown From a commercial standpoint the time taken to empty the dock, which, according to the author's paper is six hours, seems long.

In more recently constructed docks the question of the time taken in filling and emptying has received very careful consideration.

At the Tyne docks, two engines will pump out 44,000 gallons of water per minute, and the new Barry dock, which can be divided, each section holding about 16,000 tons, may be emptied in an hour.

The time question is an important element in view of the amount of money which may be saved in getting valuable steamers in and out of the dock as quickly as possible. It is a matter worthy of the attention of dock builders, and one for which full and liberal provision should be made.

The figures just given show what has been already done in this direction.

Mr. W. R. Kinipple. The dimensions of the Graving Dock were fixed by the Admiralty to accommodate the vessels of the Pacific Squadron. At that time, however, the writer considered that the dock would be too short, and too deep for commercial purposes, and therefore recommended to the Chief Commissioner of Lands and Works, B.C., that an inner graving dock for such purposes should be constructed, whenever the expansion of trade demanded it; the entrance for such inner dock to be constructed concurrent with the Graving Dock main works.

It is, therefore, very much to be regretted that Mr. Perley should have recommended the abandonment of the inner entrance as useless. If deemed advisable, it might have been constructed of a few feet greater width and depth than the dimensions shewn in the original designs, in order to accommodate the largest steamer afloat.

The construction of this inner dock could have been proceeded with at any time, and the cost would have been exceedingly small, so that a large percentage of profit would have been realized from such an undertaking.

Provision was made for pumping up the water for several feet in height above high water, so that vessels in the inner dock could be placed on high keel blocks, giving facilities for executing repairs. As the second entrance would have separated the two docks, vessels receiving extensive repairs in the upper dock would be undisturbed by the frequent dockings and undockings in the lower dock, for such purposes as scraping and painting.

A long graving dock, divided into two portions by a caisson, is regarded by most dock engineers as being exceedingly advantageous.

In the case of the Esquimalt Graving Dock, this unfortunately cannot now be done, except at great cost, owing to the abandonment of the inner entrance works at the head of the dock.

In regard to the use of Portland Cement brickwork for the inverts, culverts, and pump wells, shewn in the original designs, it may be stated that this is the general practice of English Engineers, and long experience has shewn, that wherever excellent work is required, no better materials can be used for the purpose. Of course good bricks and workmanship are necessary, and if such cannot be obtained good results need not be expected.

* * * * * * * * * * *

At the time the Dominion Government agreed to find means for the completion of the works, the coffer-dam had been completed several years, the pumping machinery, hauling gear for caisson, boilers, etc., were lying in the store ready for erection, the excavations of the main works were completed or nearly so, and the foundation and other works well advanced.

Mr. Perley.

With reference to the remarks by Mr. Kinipple, the dimensions of the dock at Esquimalt were fixed in 1877, and it was not then foreseen that, with the completion of the Canadian Pacific Railway, an entire revolution in the carrying trade in the Pacific to British Columbia would take

NOTE.—Mr. Kinipple's remarks have been abridged where shewn by asterisks.

place ; and instead of H. M. Ships being considered as the largest class of vessels to be accommodated, the large steamers plying to Japan, China and Australia would have to be provided for, and it is simply for their accommodation that an additional length of dock will be required.

When discussing the question of greater length with Sir Michael Culme Seymour, the Admiral Commanding the Pacific Squadron, the writer was assured, that for all the purposes of H. M. vessels the dock as it stands was long enough, but that for the merchant steamers of the present day it was too short, and that such is the fact is proved by the dimensions of the steamers proposed by the Canadian Pacific Railway Company.

For want of room an inner dock could not be built, and a further length of 100 feet, as suggested, is all that is required, and the question of a double dock need not be discussed.

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Mr. Bennett. In reply to Mr. Henshaw, the author is of opinion that had the coffer dam been of less solid construction than it was, it would have gone to pieces long before the dock was completed. This would have been due principally to the ravages of the sea worms, which in those waters are most destructive, and also to natural decay.

When the coffer-dam was commenced it was confidently hoped that the dock would have been opened within four years, but as a matter of fact, from various causes, it was not opened until the expiration of eleven years. The wonder is that the dam remained effective for so long a period.

As regards the foundation, the entrance works and first portion of the dock were founded on clay, the remainder and the head on rock. The harbor quay walls at the entrance were founded on clay with their shore ends on rock.

The author is not aware of any settlement of the dock side walls to any appreciable extent, but there is a small amount of leakage in the floor of the dock at its upper end, which leak developed itself after the removal of the coffer-dam. The water, it is supposed, finds its way through some fissure in the rock, which is of trap formation, and very seamy, under the western quay wall, following such seam up the dock some 300 feet before finding its egress. The floor of the dock is in no way flooded by the leak as when the dock is pumped out the water runs down the side gutters which convey it to the sump hole.

NOTE.—Mr. Perley's remarks have been abridged where shewn by asterisks.

The author deplores with Mr. Mohun that an extra hundred feet was not added to the length of the dock before the circular head, timber slides and stairways were commenced. The extension would scarcely have delayed the opening of the dock at all, but to extend the dock at a future date will be an expensive work, and will involve the extra cost of pulling down and rebuilding about 80 or 90 feet of the upper end.

The author is sorry in having to join issue with Mr. Perley in his statement that the progress of the work was delayed for the want of cement during the time McNamee & Co. were contractors for the dock. Want of this material had nothing whatever to do with the stoppage of the works then or at any other time.

The dock as designed by Messrs. Kinipple & Morris, 380 ft. in length on the blocks, met with the entire approval of the Admiralty. The second entrance at head was introduced, the writer is informed, at the express wish of the Chief Commissioner of Lands and Works of British Columbia in case a future extension might be decided upon.

It would have been very desirable to have had the pump wells and culverts built of stone, if expense had been no object, the best of bricks as manufactured in the Province being hardly what one could call first rate in quality.

The 12-inch centrifugal pump referred to was part of the contractor's plant, and was taken over by the government on completion of the works and erected so as to act as an auxiliary and be available in case of an accident to the main pumps, steam for the same being supplied by the main boilers.

The author is gratified to hear from Mr. Perley and from Mr. Summerfield that the dock is in such request that ships have to wait their turn to be docked, as this verifies the opinion the author always held that the Province in selling the dock to the Dominion Government was getting rid of a most valuable asset.

The author regrets that he seems to have understated the total cost of the docks. As far as he knew when he left Esquimalt, the outlay had been about £180,000 sterling, which is to say in round numbers *nine hundred thousand* dollars and not $800,000, as mentioned in Mr. Perley's remarks, but even this latter sum would, in the author's opinion, have been amply sufficient to have brought the work to a successful issue had it been finished outright from the start, and this notwithstanding the notoriously high rates paid for all class of labor and the heavy Customs' charges on all European and American material.

The author regrets the unintentional omission, so kindly and justly pointed out by Mr. Perley, of any reference to Sir Joseph W. Trutch,

K.C.M.G., in his connection with the Esquimalt Graving Dock as agent of the Dominion Government in British Columbia, to whose good advice and judgment the author wishes here to state he has often been indebted in overcoming many difficulties that arose from time to time during construction, and who was ready and willing at any time to give his personal attendance on the works whenever the occasion demanded.

For another sin of omission the author wishes further to apologise for neglecting to mention the names of the Honorables G. A. Walkem, A. de Cosmos, A. C. Eliot, F. G. Vernon, R. Beaven and W. Smithe, who one and all in their places as Ministers of the Crown in the Province of British Columbia, at various times up to August, 1883, did their utmost to further the progress of the dock.

Mr. Irwin seems to have failed to notice that the caisson was ballasted with upwards of 180 tons of cement concrete, which fact, however, Mr. Whited was good enough to point out.

With reference to Mr. Brown's remarks the author would merely mention that the pumps were designed for the dock as long ago as 1875, and in fact sent to British Columbia in 1876, and that since that date vast improvements in pumping machinery have been effected.

Thursday, 23rd May.

E. P. HANNAFORD, Vice-President, in the Chair.

The following candidates having been balloted for were declared duly elected as

HONORARY MEMBERS.

SIR FREDERICK JOSEPH BRAMWELL, D.C.L., F.R.S.
SIR WILLIAM THOMSON, F.R.SS. L. AND E., LL.D.

MEMBERS.

ADOLPHUS BONZANO. RUDOLPH HERING.
EDMOND BONNOR TEMPLE.

ASSOCIATE MEMBERS.

J. O. ALFRED LAFOREST. DAVID ALFRED STARR.

ASSOCIATE.

SIR DONALD A. SMITH, K.C.M.G.

STUDENT.

ERNEST PASCOE GOODWIN.

The following has been tranferred from the class of Associates to that of Associate Members.

JAMES WHITE.

The discussion on the paper on the Esquimalt Graving Dock Works, British Columbia, by W. Bennett, occupied the evening.

Thursday, 24th January.

F. R. F. Brown, Member of Council, in the Chair.

Students Paper No. 2.

LOCOMOTIVE CONSTRUCTION.

By J. P. Tuplin. Stud.Can.Soc.C.E.

Though locomotive building has long ceased to be considered an art, yet it requires the utmost attention in respect to general design, construction, and the selection of the materials; and for this reason all the principal parts should be made according to accurate drawings, templates and gauges, in their respective departments, before being taken to the erecting shop and there united. To persons who have never been engaged in locomotive building, it may seem to be a comparatively easy matter to construct an engine, when all the parts have been forged and machined; but experience teaches that a considerable amount of chipping, etc., is required. A great deal of work, such as drilling, for instance, is also needed, and this cannot be performed until the part is placed in its proper position, and consequently has to be performed by the hand ratchet.

Since the frame is the foundation of the locomotive, it will be considered first. It is generally made of wrought iron, being forged under the steam hammer and finished by the smith. The pedestals are welded to the top bar of the frame by what is termed a "Split Scarf," and when the braces are welded between the pedestals, a process called "V"-ing is employed. After these processes the frame is straightened and made to fit the template as accurately as possible. It is then taken to the machine shop, there machined and drilled, and then removed to the erecting shop.

The boiler is the most important part of the locomotive, and the useful effects of the machine depend to a large extent on its strength and efficiency. The essential features of locomotive boilers are dictated by the duties which they have to perform under peculiar conditions. The size and weight are limited by the facts that the boiler has to be transported rapidly from place to place, and also that it has to fit in between

the frames of the locomotive; while, at the same time, the pressure of the steam has to be great, in order that with comparatively small cylinders, the engine may develop great power. A large quantity of coal has to be burnt on a firegrate of limited area; and in order to utilize advantageously the heat generated, the smoke and gases of combustion are passed through a large number of tubes of 2″ outside diameter, around which the water circulates.

Wrought iron has until lately been the principal metal used in the construction of boilers, but it is now being rapidly superseded by mild steel, the thickness of which is $\frac{1}{16}$″ to $\frac{1}{8}$″ less than wrought iron. When iron is employed, the plates are generally $\frac{1}{2}$″ in. thick, and the joints lap joints. Butt joints, with a wider welt on the inside of the boiler than on the outside, are now being satisfactorily used for the longitudinal seams on some roads. In lap joints, the tendency is to open at the edges, which are therefore liable to become leaky, and there is also more corrosion than in butt rivetted joints.

Regarding the boiler as a cylinder with flat ends, the greatest strain falls necessarily upon the longitudinal seams, and the least upon the curvilinear seams, at and between the ends of the boiler. The longitudinal seams are therefore double rivetted, while the curvilinear seams, which bear only half the strain that is upon the others, are only single rivetted.

Rivet holes are generally made by punching. This rough process is objectionable for two reasons:—(1) The spacing of the holes is not perfectly accurate; (2) the metal around the hole is more or less injured by the compression and lateral flow of the material at the moment of punching.

With very soft ductile plates, the injury done in punching is comparatively small if the punch is sharp; but with rigid plates the injury is apparently serious, the plates being weakened 15 to 30 per cent. The injury is due, not to cracks formed in the plate, but to the pressure straining it beyond its limit of elasticity, and thus altering its homogenous character. The latter difficulty may be overcome by reaming $\frac{1}{16}$″ from the inside of the hole, which is then nearly equivalent to a drilled hole.

In the process of punching, through the ignorance or neglect of the workmen, the holes sometimes do not come opposite one another by one quarter of their diameter, and are then "drifted" until the sheet is fractured and the material partly destroyed. The use of drifts, although considered indispensable by many boiler makers, is productive of great evils. The result is that when the rivets are driven in, it is

almost impossible to make them fill the holes; and consequently an undue strain will come upon some of the rivets, while upon others there will be very little strain. To obviate the objections to punching, the holes are sometimes drilled. This process is in most cases more expensive than punching, but the holes are more accurate in size and spacing. On the other hand, the sharp square edge of a drilled hole appears to be unfavorable to the resistance of the rivet. It has been proved by experiment, that the resistance of the rivet is slightly increased by rounding the edges of the rivet hole.

The rivetting is done either by hand or by a machine. In the process of hand rivetting, the heads of the rivets are rarely finished till the iron is cool enough to crack under the head by the heavy blows of the hammer, and sometimes where good iron is not used the head will snap off. This is not the case with machine rivetting. Since the piston is not limited in its movements, it will follow the rivet home, drawing the plates well together, filling the holes, and making a thoroughly good joint. The iron of the rivet is given no time to cool by contact with the sheet, before it is forced into every crevice, and the hole completely filled. There is greater friction between the sheets at the joint, and consequently the shearing strain on the rivets is less in machine rivetted joints than in those rivetted by hand.

The locomotive to be considered is that known as the American type, in which there are four flanged driving wheels, and a four-wheeled truck, and in which the fire-box extends downward between the front and trailing driving axles. It will now be assumed that the parts are all ready to be put together.

The fitter receives the frame from the machine shop in four principal parts, a rearward and a forward part for each side. These are placed over and parallel with the rails, on "double jacks," which stretch across the pit. The edges of the pieces are then slightly rounded with an old file and the tapping holes tapped. The rearward parts are now turned upper side down, so that the bearings for the guard stays may be faced up. When this is done, the guard stays are fitted with red lead, and when ready temporarily fastened down, the holes for the driving bolts rosebitted, and the required studs screwed up. At the same time the joint of the back and front pieces may have been fitted. This joint requires to be an excellent fit, and is therefore filed carefully until red lead shows a good bearing. The frames are now turned back to their proper position, the holes for the splice bolts rose-bitted, and the splice-bolts cautiously driven up with a flogging hammer and a set. These bolts are all to be a hard driving fit; there are five of them in each splice, each

one inch in diameter, and they are provided with jam nuts. Each side being now virtually one piece, temporary tie-bars are put across from side to side. These hold the frames loosely, giving about an eighth of an inch play, or $\frac{1}{16}$" on each side. The keys in the splices may be put in their places at any convenient time. These keys enter key-ways whose sides are parallel, and their action is to relieve the splice-bolts of the tendency they have to shear. They are made of good wrought-iron, and there are two of them to each splice. To fit a key, first calliper the height of the key-way, and grind the key so that its thickness will be about $\frac{1}{32}$" less than the height of the keyway. These sides, *i.e.*, top and bottom of the key, must be parallel; for if the key were tapered in this direction, it would tend to separate the splice-joint, and so throw a strain on the splice bolts, which might break their threads. The sides of the key should have a very slight taper, and should be fitted so that the small end of the key should barely enter the key-way. The key is driven in with a flogging hammer and set, and the ends chipped neatly and filed down. All through the work in the splice, everything should be a driving fit, and in fact the same applies to nearly all work on the frames. We are now ready for the foot plate, which is lowered by the traveller into its place at the rear end of the frame. Here the two sides pieces of the frame are accurately placed in correct position with regard to one another.

Their top surfaces are placed in the same horizontal plane, by means of a spirit-level and the jacks on which they rest. The planes of the first and third horns are perpendicular to this plane. Find the lines in which the planes of the horns and that of the upper surface of the frame intersect, and scribe them. Take a point at a distance of about an inch from the inside surface of the frame, on each of those four lines, and make light centre punch marks. With the beam compasses, try whether the two points on each side of the frame are the same distance apart. If they are not, there must be some error in the marking out, if the machining is done correctly, which has been taken for granted. Rectify the mistake, until the distances are found to be the same. Now try the distance of the four points diagonally, and if they are not equal, one of the sides must be moved back or forward, as the case may be, until the distances are the same. The frame is now perfectly square, clamp the foot-plate to the frame, rose-bit the holes, and bolt the plate securely to the frame, generally with seven-eighth inch bolts in this operation. The front ends of the frame are rested on jacks to support the saddle casting which has now to be dealt with. It is lowered into place upon the front of the frame, fitting into a sort of slot on each side, and is pushed as far back as possible. It should

fit close up against the frame at the back; but if it bears on one side only, the end of that slot on which it bears must be chipped and filed until it bears properly on both sides. Drive a couple of flat chisels between the front ends of the slots and the saddle casting to tighten it back, and rose-bit the holes from underneath. These holes go through the frame and the casting. Lower the cylinder castings into position, and temporarily bolt them down. To find if the cylinders are "*in line*," fasten a string in the centre of the forward end of the cylinder. Go to the back of the frame, and fasten the other end of the string to a rod of iron, projecting from the side of the frame, so that the string may be horizontal. Now shift the string at the back end of the frame until it passes exactly through the back end of the cylinder, which may be shown by means of a pair of callipers. This string also passes through the centre of the front end of the cylinder, therefore it passes along the axis of the cylinder bore. Now take the distances of the string from the frame at the cylinder mouth, at the middle of the frame, and at the back end of the frame. If these distances do not differ more than $\frac{1}{32}$" the cylinder is accurate enough for all practical purposes, but if the difference is greater than this the cylinder casting will have to be taken down, and some of the metal filed from the end which throws the line farthest from the frame. This operation is repeated until the axis of the cylinder and the plane of the side of the frame are parallel. The cylinder is now strongly and tightly bolted to the saddle casting with temporary bolts. The next operation is to find if the valve seat is horizontal. If the spirit-level shows that one end of the valve seat is higher than the other, it must be lowered, and chipped or filed on the places which raise it out of the horizontal, until it is found, by trying it up, that the surface is perfectly horizontal. Now rose-bit all the holes in the cylinder casting, drive in the bolts and nut them. Each cylinder is bolted to the frame and also to the flange of the saddle casting, by six one-inch bolts. The cylinders are also each bolted to the saddles by ten one-inch bolts. Two keys are now driven in between the front of the saddle casting and the slot in the frame. These keys are made wider at the bottom than at the top, so as to prevent them from working up, and have no taper in their length.

The horn blocks which form the wearing surfaces for the axle-boxes may now be fitted at any convenient time. The inside faces of the horn blocks are filed and fitted with red lead to the horns, and the faces are levelled up by means of a surface plate, so as to be in the same plane. Lay a straight edge across their faces, and if it bears

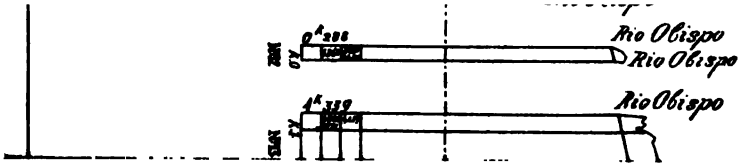
evenly along them they are correct. If it does not bear evenly, the surfaces will have to be filed until the straight edge shows them to be all right. They are then fitted to the axle boxes, after which they are bolted up with countersunk bolts, one in each. The third pair are fitted in the same way. The wedges, *i. e.*, the second and fourth pair, are also fitted in a similiar manner; each is then fitted so that its face is parallel to that of its fellow block. The frame proper is now complete, and ready to have the boiler lowered into position. Pieces of timber and wedges are now laid across the pit, and the boiler is lowered by the traveller, until the fire-box rests upon these, and the smoke-box upon the saddle casting, the face sheet being about one and a half inches from the front of the foot plate. The wedges upon which the fire-box rests are so adjusted as to make the axis of the cylindrical portion of the boiler horizontal. It is very important that the smoke-box should bear on both the front and back flanges of the saddle casting, and also that the axis of the boiler should be horizontal, taken in its required position. To insure these requirements, measure the distance from the top of the frame to the centre line of the boiler. Chalk the outside of the flanges of the saddle casting, and taking this distance on a pair of dividers, scribe lines along each of these flanges, carefully keeping one leg of the dividers constantly touching the smoke-box. These lines will show the amount which has to be chipped off the casting. The front of the boiler is now lifted up to allow the chipping to be done, and as soon as the metal has been chipped down to the lines, a thin layer of red-lead putty is spread over the chipped surface, upon which the smoke-box is to rest, and the boiler is again lowered till the smoke-box rests upon the saddle. The wedges are now so adjusted behind, that the boiler sits in its required position. The next process is to secure the boiler at the back. This is done by means of six expansion brackets on each side, four on the upper, and two on the lower bar of the frame. They are fastened to the fire-box by seven-eighth studs, screwed into the firebox, and nuts. Holes are now drilled through the smoke-box to correspond with the holes in the saddle, and the former is bolted to the latter by sixteen one-inch bolts. The boiler is now perfectly secure. There are two tie bars which cross from frame to frame, one in front of and the other behind the front axle-box. These are placed there to keep the frames at a fixed distance from one another in the middle, just as the foot plate and the saddle do at either end. They have slots cut in them so as to fit down over the frames, and are fastened down by means of two one-inch studs in each end. These studs are jam-nutted. We are now ready to put up the motion plate which is

attached to the frame by two angle irons. Place these angle irons on the frame, one on each side, drive in the bolts, and screw them up tight. Try the other surfaces with a square to see if they stand exactly perpendicular to the frame. If either is out at the top or bottom, it will have to be filed until the square bears all the way up. Clamp the motion plate to these angle irons, and if the holes do not come exactly opposite in each, run a rose-bit through them, drive in the bolts, and screw them up tight. Now see that the slots in the bottoms of the rocker-boxes will fit down over the frames, and when ready, bolt them to the frames in their correct position by means of driving bolts. These boxes need to be adjusted with a great deal of accuracy, as any slight divergence of the rockers from correct lines would derange the whole valve gear. The bearings for the reverse shaft, one being placed upon each end of the shaft, are now clamped to the frame in their respective positions, and after the holes are rose-bitted are secured firmly to it by driving bolts provided with jam nuts.

The brasses, if not in position, may now be screwed into their respective apertures. Three "try-cocks," two gauge-glass cocks, and a steam gauge cock are screwed into the face sheet. Two tallow-pipe valves and a large double valve, which supplies steam to the injectors, are screwed into the top of the boiler, where it extends into the cab, and a check-valve is screwed into the barrel of the boiler on each side, about two feet from the front tube sheet. The mud plugs are also screwed into their places.

The next operation is to introduce the steam pipes. Before putting them in, however, the joints which they make with the T pipe and the saddle casting have to be "*ground in.*" To render each joint steam-tight, two brass rings flat on one side, the other forming part of the surface of a hemisphere, are placed between the end of the steam pipe and the T pipe or saddle casting. Thus a sort of ball and socket joint is formed, the flanges of the pipes being secured by bolts. Each ring has its concave surface ground to the socket in the part to which it has to fit. The flat surfaces of these rings are scraped and tried upon a surface plate. The grinding material which is used is a mixture of oil and emery. To grind in a ring, cut a block of wood to a circular shape, the diameter of which shall be a fraction larger than the internal diameter of the ring, and nail a narrow strip of wood across this to form two handles. Now drive this block inside of the ring, and rub the surfaces of the ring and the socket with the oil and emery. Revolve the ring backward and forward a number of times, remove it, and again spread the oil and emery

evenly over the surfaces; revolve the ring as before, then turn it through half a revolution, and repeat the operation until the two surfaces touch all the way round. All the steam pipe joints are ground in this way, after which the pipes are put up in their places, the rings after having been thinly coated with black varnish are inserted in their places, and pipes secured firmly by bolts. The exhaust nozzles and steam pipes are then bolted to their respective places. The edge of the fire-hole is next chipped, and tried up with a wooden face-plate until it shows a pretty good bearing surface; after which the fire-door is secured to its place, being fastened to the boiler by a hinge. The running board brackets are also secured to the boiler each by two studs. We are now ready to put up the spring gear; but before doing so, it is always advisable to fit the several parts together, so as to prevent any delay when once the work is started. The cotters must be tried in their respective places, and the brackets in the springs. The fulcrum is then placed in its proper position on the top of the frame, the holes which go through it and the top bar of the frame rosebitted, and the bolts driven in from below and tightened up. There are generally four bolts in each of these fulcra, varying from one inch to one and one-eighth inches diameter, and they must be a good driving fit. The saddles, which have previously been fitted to the tops of their respective axle-boxes, are now placed upon the frame in their respective positions, corresponding to the position of their axle-boxes. These saddles are made of cast iron, and are four in number. A spring is now placed upon each of these, the brackets are put up and secured by cotters. The equalizing levers are also put up and secured to the ends of the springs. The fulcrum goes through the equalizing lever, and the latter is prevented from rising by means of a cotter which goes transversely through the fulcrum. The lever is next drawn down so as to allow the cotter to be inserted in its place. This generally requires a good deal of power, as the springs have to be straightened a little in the operation. A hook of heavy iron is placed over each end of the equalizing lever near the ends, in the other end of which is an eye. Into each of these eyes large crow-bars are inserted, and by pushing them under the top bar of the frame a certain leverage is obtained. Three or four men now put their weight upon the other ends of each of these bars at the same time, and so they draw the equalizing lever down until the cotter can be inserted in the fulcrum. Their services are then dispensed with, and the hooks and crow-bars taken away. The lagging may be put on at any convenient time, as well as the cab, running board, etc., after which the engine is wheeled.


Rio Obispo
Rio Obispo
Rio Obispo

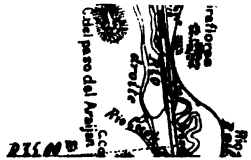
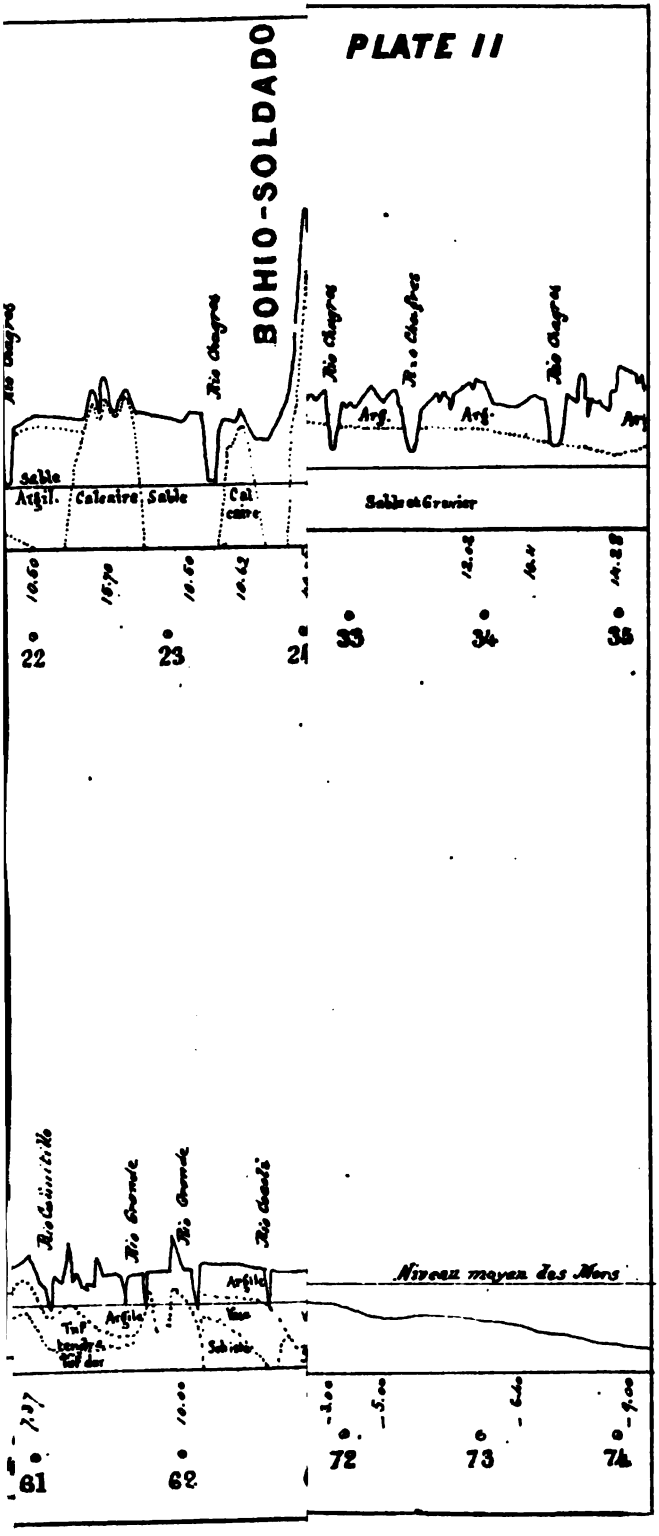
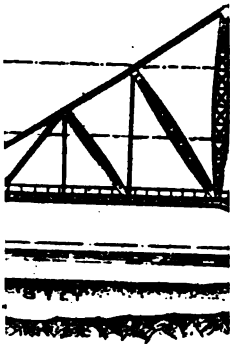

Rio

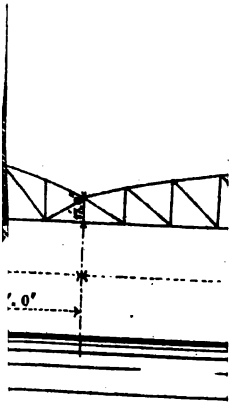
PLATE II

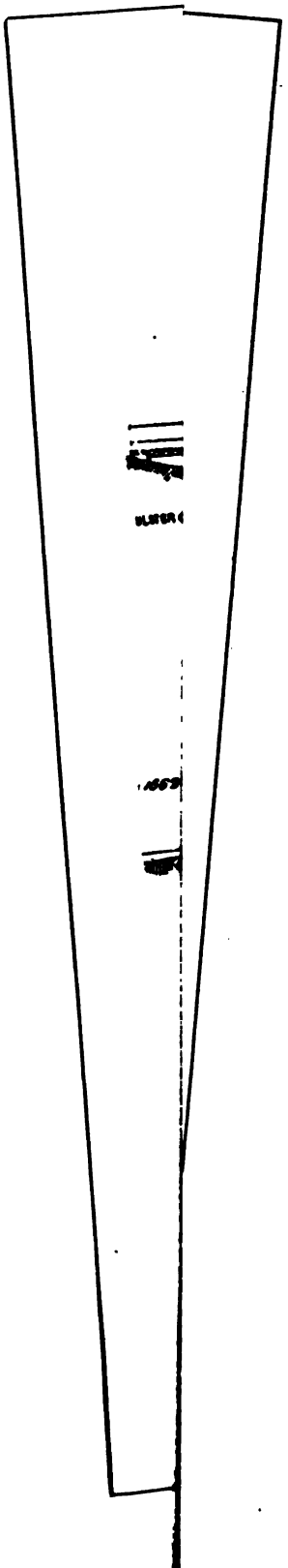

BOHIO-SOLDADO
Rio Chagres
Rio Chagres
Rio Chagres
Rio Chagres
Rio Chagres
Arg.
Arg.
Arg.
Sable
Argil.
Calcaire
Sable
Cal caire
Sable et Gravier
10.60
15.70
10.60
10.42
12.08
14.42
14.28
22
23
24
33
34
35
Rio Grande
Rio Grande
Rio Grande
Argile
Argile
Tuf
Sable
Niveau moyen des Mers
-7.97
10.00
-3.00
-5.00
-6.00
-9.00
61
62
72
73
74

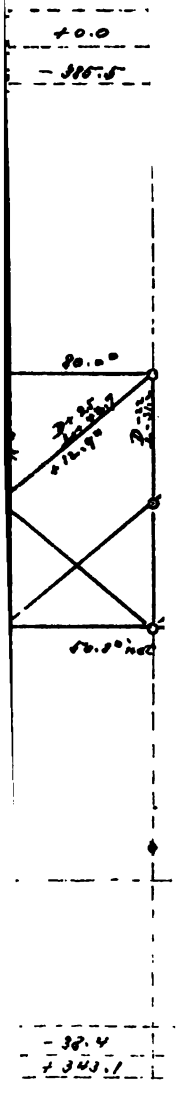
Sukkur.



Hooghly.



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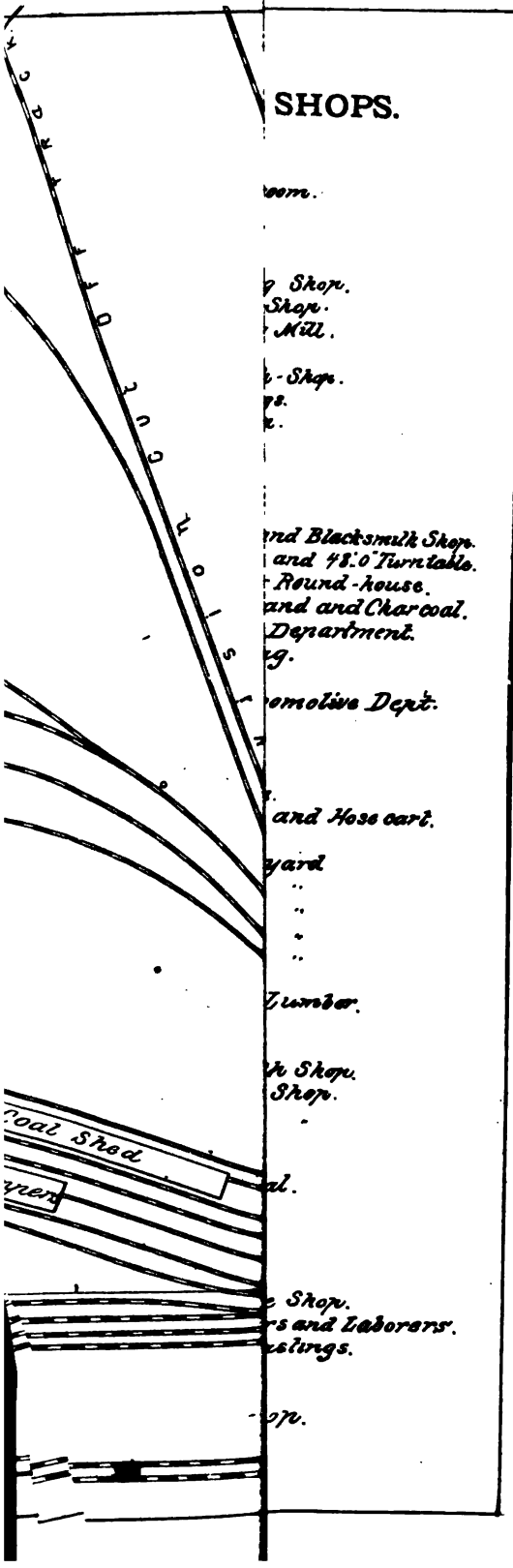
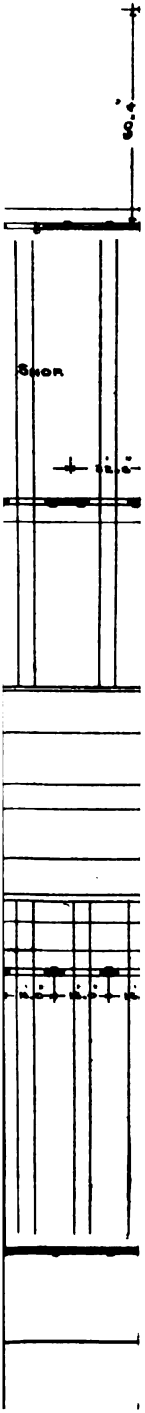
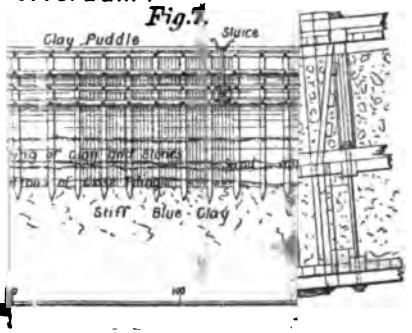
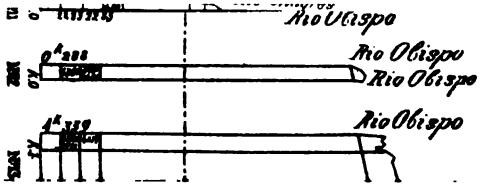

SHOPS.
Coal Shed


SHOR

Cofferdam.

Fig. 1.




Rio Obispo
Rio Obispo
Rio Obispo
Rio Obispo

Miraflores
Rio
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Cdor. paso del Arrajan

ERRATA.

VOL. II.

Page 386, *line* 36, *for* "bag" *read*, "day."
" 426, " 4, " "ninety" " "one hundred and eighty."

VELOCITY OF FLOW DRAINAGE AND IRRIGATION DITCHES.

Slope	Width	Fall	Depth				
½ to 1	3	7′	3	*For*	2.449059	*Read*	1.449059
1 to 1	5	5	1	"	1.826846	"	0.826846
1½ to 1	4	6	1	"	1.809246	"	0.809246
1 to 1	16	1.5	8	"	3.4829	"	2.4829
1 to 1	20	1.5	2	"	1.967598	"	1.697598
1½ to 1	10	1	10	"	1.734161	"	2.734161

Page 443, *line* 6, *for* "siderest" *read* "sliderest."

VOL. III.

Page 286, *line* 11, *for* "Sulphate" *read* "Sulphite."
" 289, " 12, " "slit" " "split."
" 289, " 16, " "Fibre Cellular" " "Fibro Cellular."
" 289, " 39, " "black liquor" " "back liquor."
" 291, " 27, " "bisulphate" " "bisulphite."
" 293, " 35, " "$16.98" " "$15.98."
" 294, " 21, " "bisulphate" " "bisulphite."

INSTRUCTIONS FOR PREPARING PAPERS, ETC.

In writing papers, or discussions on papers, the use of the first person should be avoided. They should be legibly written on foolscap paper, on one side only, leaving a margin on the left side.

Illustrations, when necessary, should be drawn on tracing paper to as small a scale as is consistent with distinctness. They should not be more than 10 inches in height, but *in no case* should any one figure exceed this height. Black ink only should be used, and all lines, lettering, etc., must be clear and distinct.

When necessary to illustrate a paper for reading, Diagrams must be furnished. These must be bold, distinct and clearly visible in detail for a distance of thirty feet.

Papers which have been read before other Societies, or have been published, cannot be read at meetings of the Society.

All communications must be forwarded to the Secretary of the Society, from whom any further information may be obtained.

The attention of Members is called to By-laws 39 and 40.

Thursday, 10th October.

P. A. PETERSON, Vice-President, in the Chair.

Paper No. 32.

BRIDGE CALCULATIONS.

By H. E. VAUTELET, M.CAN.SOC.C.E.

The opinion of many well known authorities is that it would be preferable to use a distributed load, that would be safe for all existing types of locomotives in use on railways, and that would leave a margin for the probable increase of weight in the future. The wheel base of a locomotive as well as the weight on each axle is limited by the radii of the curves and the section of the rail; and although the weight of cars is constantly increasing, there exists a necessary relation between the engine and train weights. In general practice, the train weight is considered as distributed and the engine weight as concentrated. The author thinks that the weight of a wheel is always distributed by the rail and ties (more so in locomotives than in cars, owing to the lesser distance between the wheels), and that both weights should be considered as distributed. It will always be necessary to use two different distributed loads, and the equivalent distributed load will vary with the length of span.

Furthermore the stresses, although calculated with the greatest care, are not the actual stresses in a bridge, and frequently discrepancies, amounting to several thousand pounds, are shown during the erection. The general practice is to have the posts fastened by pins or rivets, allowing them to work as tension members, while the top chord is rigid, instead of having articulations at every panel point. It follows that the strains are not what they would be in an articulated system, where the posts could only take compression, the differences being more especially apparent in bridges with inclined top chords, which act partially as an arc, the posts acting as suspenders. Another cause of error is the use of stringers, rivetted to the floor beams, which act as parts of the top or bottom chords, as the case may be.

It must not be supposed that the author is advocating free articulations with bolted stringers and slotted holes, as he believes that the actual practice increases the solidity of the bridges, and prefers to have stiffness in his work, at the cost of some uncertainty in his calculations. He would also follow in the lead of an eminent bridge engineer in the United States, whose trusses are rather light, a large quantity of material being used in the stiffening of the bridges, in the top and bottom laterals, sway bracing, and especially in the portals, the last of which is certainly a very important part of a bridge. Most of the actual specifications seem to be made for the perusal of outsiders more than for actual use, and it seems (to give one instance) that the rivetting foreman and inspector should know, without being told, what the appearance of a rivet must be after it is driven.

In treatises on bridges, written by French authors, it is always said that we must not rely too much on calculations, and the best that can be said about their rules is that bridges built according to them and with a large factor of safety have withstood the test of time.

Experience would appear to show that, usually, the longer the specifications the worse are the bridges. What may be considered to be a standard bridge in the United States is built with a two page specification.

This paper sets forth solutions of the two following problems, which the author believes to be new :—

To find the maximum bending moments and shearing stresses in girders or trusses :—1° taking into account a distributed engine load, followed and preceded by a distributed train load, and 2° taking into account the load on every wheel. A simplification in the calculation of bending moments, in continuous bridges of two spans, will also be referred to.

1° Calculation of the maximum bending moment with a distributed load P, occupying a length V, preceded and followed by a distributed load p.

Let y be the bending moment at C

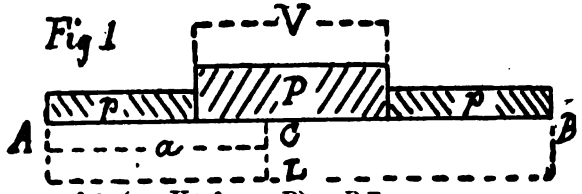
$$y = -x^2 \left(\frac{P-p}{2}\right) + x(P-p)\left(1-\frac{V}{L}\right)a - (P-p)\left[\frac{V^2 a}{2L} - V\right]$$

$$-\frac{Pa^2}{2} + \frac{pLa}{2}$$

$$\frac{dy}{dx} = -x(P-p) + (P-p)\left(1-\frac{V}{L}\right)a$$

If y is to be a maximum $\frac{dy}{dx}=0$ and $x = a\left(1-\frac{V}{L}\right)$ *

Fig 1



Hence, $y = -a^2\left[\left(1-\frac{V}{L}\right)^2\left(\frac{p-P}{2}\right)+\frac{P}{2}\right]$

$$-a\left[\frac{PV^2}{2L}-PV-\frac{pL}{2}+pV-\frac{pV^2}{2L}\right]$$

$$\text{or } y=\left[\left(1-\frac{V}{L}\right)^2\left(\frac{p-P}{2}\right)+\frac{P}{2}\right]\left[aL-a^2\right]$$

If instead of two weights P and p a weight R is distributed,

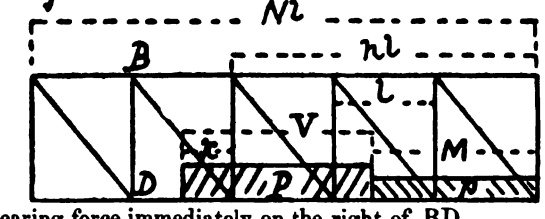
$$\therefore y = \frac{R}{2}(aL-a^2)$$

The weights P and p can then be replaced by a weight R such that

$$R=\left(1-\frac{V}{L}\right)^2\left(p-P\right)+P$$

$$\text{or } R = P-(P-p)\left(1-\frac{V}{L}\right)^2$$

Fig 2



The shearing force immediately on the right of BD

$$=\frac{VP(x+nl-\frac{V}{2})}{Nl}+\frac{M^2p}{2Nl}-\frac{Px^2}{2l}$$

$$=-x^2\frac{NP-p}{2Nl}+x\frac{VP+(nl-V)p}{Nl}+\frac{VP(nl-\frac{V}{2})}{N}+\frac{(nl-V)^2}{2Nl}p$$

Since $M = x+nl-V$

If the shearing force is to be a maximum

$$\therefore x=\frac{V(P-p)+nlp}{NP-p} \text{ or } \frac{Px}{l}=\frac{VP+Mp}{Nl}$$

* This formula has been used, if the writer is not mistaken, by the Keystone Bridge Co.

with the condition

$$V < n + nl$$

$$\text{i.e., } V < \frac{NPnl + V(P-p)}{NP-p}$$

$$\text{or } V < \frac{N.nl}{N-1}$$

Hence max. shearing force

$$= \frac{V(P-p)[2NPnl - VP(N- \ )] + Nn^2{}^2Pp}{2Nl(NP-p)}$$

For a uniformly distributed load the max. shearing force $= \frac{n^2Rl}{2(N-1)}$

Hence, that these two shearing forces may be equal,

$$R = \frac{(N-1)P}{NP-p}\left\{P - (P-p)\left(1-\frac{V}{nl}\right)^2 + \frac{(P-p)V^2}{Nn^2l^2}\right\}$$

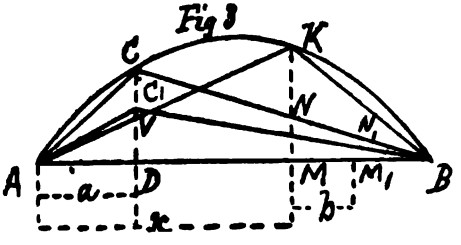
By taking

$$R = P - (P-p)\left(1-\frac{V}{nl}\right)^2$$

we have a close approximation on the safe side. The weights P and p can be replaced without material error by one weight R; V being the length occupied by the distributed load P, and n the number of panels which must be fully loaded to give the maximum stress.

2° Graphic calculation of bending moments, taking every wheel into account.

Fig 3



If a weight P is moving along AB, the bending moment at the point of application will be:

$$y = \frac{P(l-x)}{l}x$$

Having drawn this parabola, the bending moment at a point D at a distance a from A will be:

$$y = \frac{P(l-x)}{l}a$$

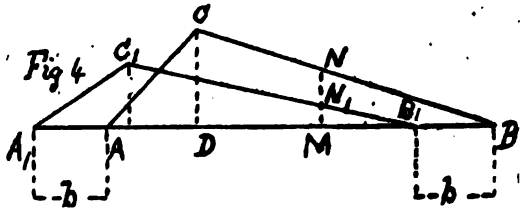
and CD being an ordinate of the parabola for an abscissa $x = a$

$$CD = \frac{P(l-a)}{l} a$$

In the triangle ACB we have:

$$MN = CD\frac{l-x}{l-a} = P\frac{l-x}{l}a = y$$

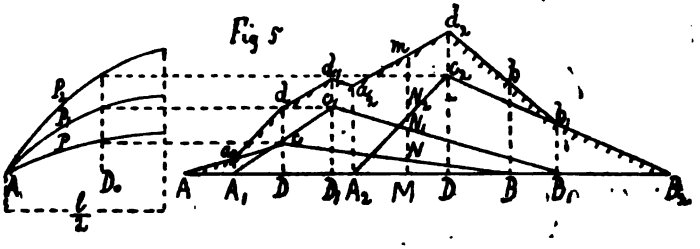
The bending moment at D is then equal to the ordinate of the triangle ACB at the point of application of the weight P. For another load P_1 we should have another triangle AC_1B_1, and if b is the distance between the two weights, $MN + M_1N_1$ will represent the bending moment at D produced by the weights P and P_1.



By sliding the triangle AC_1B a distance b to the left, M_1 comes to M, and the bending moment at D for any position of the two weights is given by the ordinates $MN + MN_1$ of the two triangles.

The same reasoning will apply to any number of weights.

To apply the method it is sufficient to draw the $\frac{1}{2}$ parabola $= P\frac{(l-a)}{l}x$ to a convenient scale.



To find the moments at D_0 draw a series of triangles ABC, $A_1B_1C_1$ $A_2B_2C_2$ etc., so that

$AD = A_1D_1 = A_2D_2 = A_0D_0$

$AB = A_1B_1 = A_2B_2 =$ length of span l.

AA_1, A_1A_2,... being the distances between the weights.

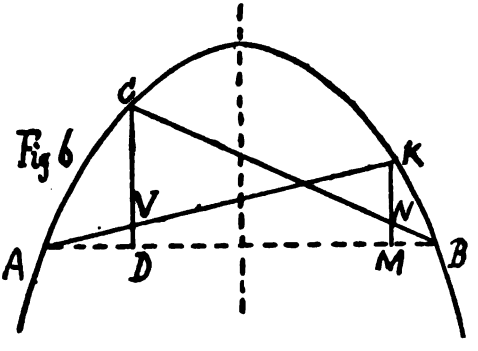
As $AA_1A_2 = BB_1B_2 = DD_1D_2$ it will be convenient to have these distances on a scale, and the whole series of triangles may be drawn very quickly for every point at which the bending moment is required, and the sum $MN + MN_1 + MN_2$ will represent the moment at Do when the weight P_2 is at M.

Now consider a motion of the weights between two consecutive apices. Each abscissa increases or decreases in proportion to the distances moved, and it is necessary to reach an apex so that one of the increasing abscissæ may decrease. A maximum can then only be reached at an apex, *i. e.*, when one of the weights is applied at D_o. It will then only be necessary to consider the ordinates at the different apices, and a curve $B_2\ b_1\ b\ d_2\ m\ a_2\ a_1\ d\ a_1\ A$ may be drawn whose ordinates will represent the bending moments at D from the time P_2 enters the bridge until the P leaves it.

This solution brings forth a property of the parabola that the writer has never seen mentioned before, and whose limits can be enlarged by analytical demonstration.

Draw the triangle AKB (fig. 6)

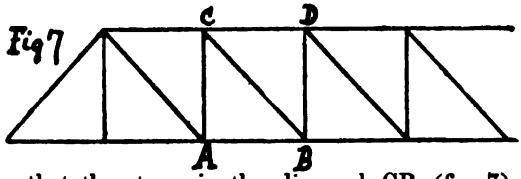
$$KM = \frac{R(l-x)}{l}x \text{ and } VD = \frac{P(l-x)}{l}a = MN$$



Join (fig. 6) two points C and K of a parabola to the points of intersection B and A, and of a perpendicular to the axis. The lengths VD and MN are equal.

3° Graphic calculation of stresses in the members of a truss, taking every wheel into account. This calculation is based on the two following theorems, for which the writer is indebted to Mr. Joseph Meyer, of the Union Bridge Co.

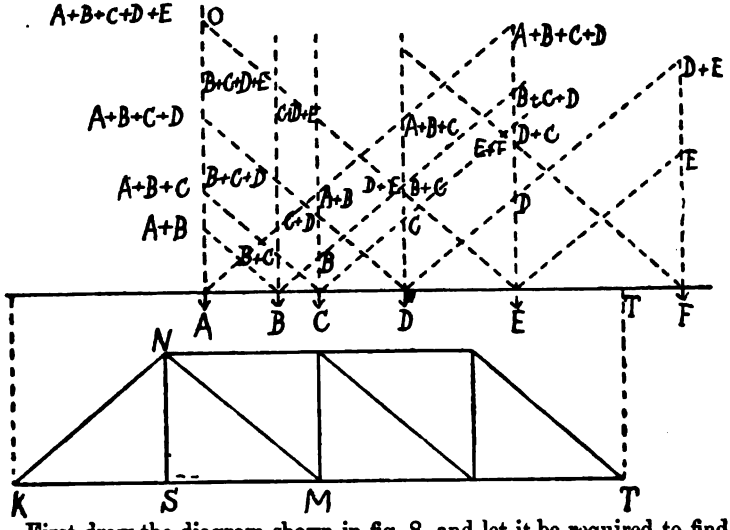
Fig 7



In order that the stress in the diagonal CB (fig. 7) may be a maximum, the weights on the left of B, including the weight at B, must be greater than the sum of all the weights on the truss divided by the number of panels.

In order that the stress in AB (fig. 7) may be a maximum the sum of the weights on the left of A, not including the weight at A, divided by the number of panels on the left, must be less than the sum of the weights on the bridge divided by the number of panels in the truss.

Fig 8



First draw the diagram shown in fig. 8, and let it be required to find the sum of the weights on truss K T, and the sum of weights on the left of M. The first sum is given at O by following the diagonal E O and the second sum at V by following the diagonal A V. By moving the truss so that M occupies the different positions A B C, etc., it will be easy to find the most unfavorable situation of the load by applying the theorems given before.

Now let M_2 be the bending moment at M

R the reaction at K

M_1 the moment in relation to M of the weights on the left of M.

Let l be the panel length

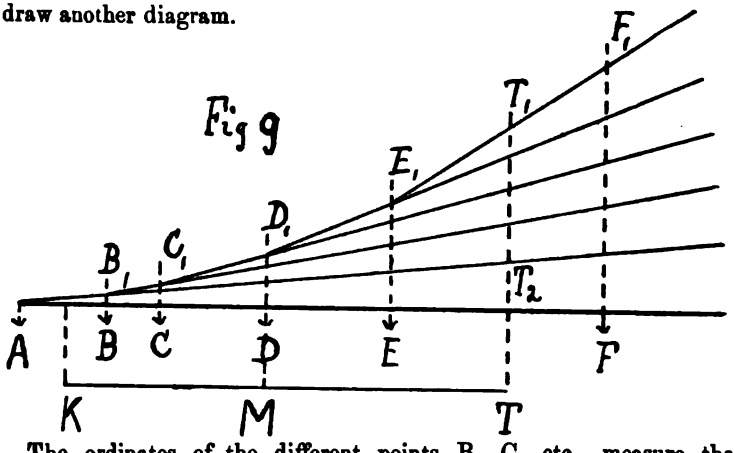
N " number of panels in truss

n " " " left of M

$M_2 = R \times n\, l - M_1$

$= (R \times N\, l)\frac{n}{N} - M_1$

$MN = R - \frac{M_1}{l} = \frac{\frac{(R \times N\, l)}{N} - M_1}{l}$. In order that M N may be a maximum a part only of M S is usually loaded and we then only require to know the quantities R × N l and M. To find those values we will draw another diagram.

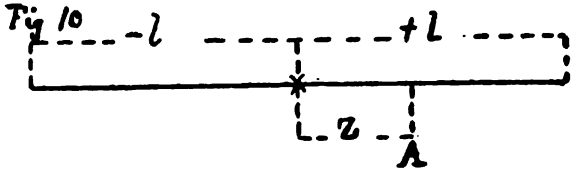


The ordinates of the different points B_1 C_1 etc., measure the moments in relation to B, C, etc., of all the weights at the left, and if we want to find the values R × N l and M_1 when M is at D and the ends of the truss at K and T_1, M_1 will be measured by D_1 D_2 and R × N l by T_1 T_2

Bearing in mind that for a distributed load the polygonal curve AB_1 C_1D_1 becomes a parabola, many interesting properties of the parabola may be demonstrated.

4° Bending moments in continuous bridges of two spans.

The maximum bending moments at each point are given by considering three cases of loading, viz., each span loaded and both spans loaded.



The maxima are then given by the line

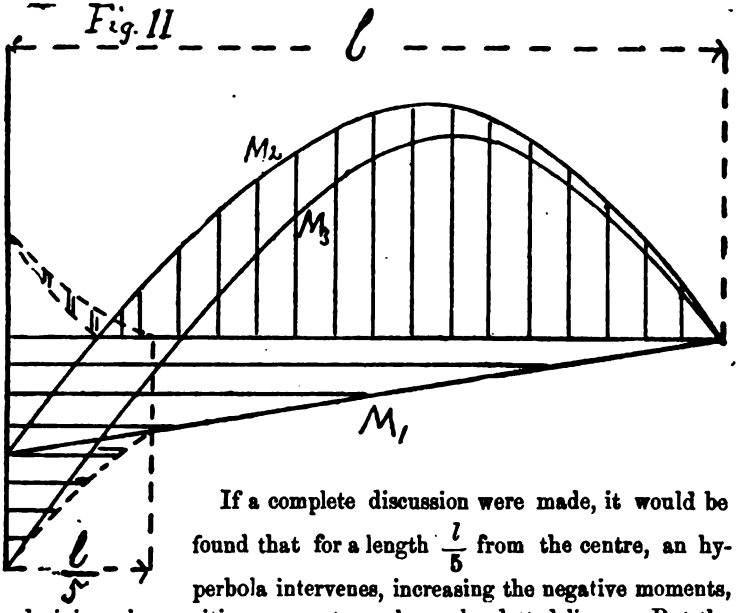
$$M_1 = \tfrac{1}{16}\, pl(l-z) \qquad (1)$$

and the two paraboloæ

$$M_2 = \frac{z}{16} pl\,(l-z) - p\frac{(l-z)^2}{2} \qquad (2)$$

$$M_3 = \tfrac{8}{16}\, pl(l-z) - p\frac{(l-z)^2}{2} \qquad (3)$$

Fig. 11

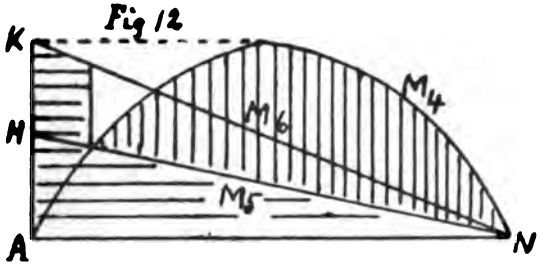


If a complete discussion were made, it would be found that for a length $\frac{l}{5}$ from the centre, an hyperbola intervenes, increasing the negative moments, and giving also positive moments as shown by dotted lines. But the results would not be materially changed.

If M_4 is the bending moment produced by a distributed load p on a single span l we have a parabola

$$M_4 = -\frac{pl}{2}(l-z) - \frac{p\,(l-z)^2}{2}$$

Fig 12



If AH = HK the lines NH and NK are

$$M_5 = \frac{p^1}{16}(l - z) \text{ and } M_6 = \frac{pl}{8}(l - z)$$

and it is easy to see that

$$M_2 = M_4 - M_5$$
$$M_1 = -M_5$$
$$M_3 = -(M_6 - M_4)$$

which gives an easy method to have the bending moments.

The author thinks that the first formula given may have some practical value, and he would like to have the opinion of bridge engineers about it, as well as the opinion of mechanical engineers as to the value to be given to the constants.

The coefficients to be determined are P, p and V. In the Canadian Pacific Ry. specification p is taken at 3000, and in calculations of many bridges the writer has taken P = 3730 and V = 105'0" and has found very little difference when taking every wheel into account.

For spans under 105 feet and over 21 feet he has taken

$$P = 4600,\ p = 3240,\ V = 21'\text{–}0''$$

and the formula becomes

$$R = 3730 - 730\left(1 - \frac{105}{nl}\right)^2 \text{ for spans over } 21'$$

$$R = 4600 - 1360\left(1 - \frac{21}{nl}\right)^2 \text{ for spans over } 21'$$

$$R = 4600 \text{ for spans under } 21'$$

DISCUSSION.

Mr. Shelford. The writer has read Mr. Vautelet's paper, on Bridge Calculations, with considerable interest; and on comparing his formula with a table, in accordance with which the writer has built a number of bridges in the last few years, finds that it agrees fairly well.

This table is to be found in the Minutes of Proceedings of the Institution of Civil Engineers, Volume 82, Page 349, and probably represents the latest practice in England, where no larger work than the Hull & Barnsley Railway, for which the writer was Chief Engineer, has been constructed for many years.

At the Birmingham Meeting of the British Association in 1886, the writer, jointly with Mr. A. H. Shield, Associate Member Inst. C.E., read a paper on the design of Girder Bridges, which the Committee did them the honor to print *in extenso* in their Proceedings.

Mr. A. Shield. The author's first formulæ are of considerable interest, and afford a ready means of computing the stresses resulting from hypothetical distributed loads of different intensities, of which the extent of the load of greater intensity (and the intensities of the loads) is defined. It remains, however, to determine the values to be assigned to the intensity and extent of the distributed engine load P, in order that the formula may give results which will cover the stresses produced by the actual loads. In this respect a sign of weakness is apparent in the change made by the author in the values of P and V, when the span reaches 105 feet. The expression $R = 4{,}600 - 1360 \left(1 - \frac{V}{nl}\right)^2$ for spans from 21 to 105 feet takes into consideration the load due to one engine only (although it is usual to specify for two), and its limit of application is therefore about 55 feet. Beyond this length with a load specification of two engines of the usual type, there are two distributed loads of (say) 4,600 lbs. per foot run for lengths of (say) 21 feet, with a definite interval between them in which the load is (say) 3,000 lbs. per foot, and preceded and followed by a similar train load—a condition which is not covered by the formulæ.

Having regard to the difficulties which attend the application of the author's formula, in the determination of the co-efficients and the limits of its applicability to spans, which either admit only one engine, or are

so great that the weight of two engines with their tenders may, without sensible error, be considered as uniformly distributed, the writer would suggest that a readier method of obtaining an equivalent uniformly distributed load of practical utility is to determine, by actual computation, for a series of spans, the uniformly distributed loads which give moments at any point in a beam equal to or exceeding those produced by a given specified system of loads, or by two or more such specified systems. These equivalent loads laid down upon a diagram, with the spans for abscissæ, give a series of points to cover which a more or less angular curve may be drawn.

Referring to the second part of the author's first formula, viz., that relating to the equivalent for shearing stress, it is to be noted that the result obtained by the author, as an approximation to the case of a truss bridge, may be directly derived from the previous expressions for bending moments, and if so derived takes the form

$$R = P - (P-p)\left(1-\frac{V}{L-a}\right)^2$$

This expression shews perhaps more clearly than the form

$$R = P - (P-p)\left(1-\frac{V}{nl}\right)^2,$$

that in using an equivalent uniform load to estimate shearing stress, such equivalent must be determined separately for estimating the shear at each apex or panel, and is for each such apex equal to the equivalent uniform load for a span equal to the length of that portion of the bridge, which must be loaded to give a maximum shear at that apex—*i.e.*, nl or $L-a$.

Prof: Burr. The wisdom of using arbitrary weight concentrations, more or less like those of locomotives and tenders, in the design of railway structures, is being widely questioned by engineers, and most properly.

In the United States the matter has been receiving increasing and serious attention for several years past, and it seems probable that a more simple and equally accurate system will, at no remote date, be followed to a very considerable extent. The present system is certainly most wasteful of time, and the results are no more approximate in character than those reached by a much more simple and equally rational method. The constantly varying and increasing locomotive and tender wheel weights completely neutralize the accuracy of the best present methods, with weight concentrations, and render nugatory the extravagant expenditure of time in computations. Such a system cannot be too quickly changed; but it should not be supplanted by another

equally objectionable. If the writer understands the first paragraph of Mr. Vautelet's paper, particularly the last sentence, he would propose to use an "equivalent distributed load," which "will vary with the length of span."

In the first place, there is, in fact, no such thing as a uniform load equivalent to a given system of concentrations. The maxima stresses due to the latter in every chord panel and web member would, in the general case, each require a separate and independent "equivalent uniform load."

In the second place, even if such an equivalent uniform load were a possibility, it would require a very considerable computation for each different system of concentrations. In any case the method would effectually defeat its purpose. This matter of equivalent uniform load has been most thoroughly considered by many of the engineers of the United States within the past few years, and with rare exceptions the method has been rejected as entirely inadequate to accomplish the desired results.

It has frequently been shown, however, particularly by Mr. Geo. H. Pegram, C.E., of St. Louis, that a simple uniform load with a single concentration at its head (or at some intermediate point, if the locomotives are so placed) will produce essentially the same stresses as the same uniform train load headed by two locomotives, or with the same locomotives placed at some intermediate point. Nothing could be simpler than such a system of loading, and the single concentration can be easily inferred from the locomotive weight. The method resulting from the use of such loading is now receiving very favorable attention from many quarters, and its early introduction is not unlikely.

Regarding the particular equations found by Mr. Vautelet, it is to be observed that while their forms may be new, his method has long been used in the engineering office of the Phœnix Bridge Co., as well as in those of other American bridge companies; in fact the general method for parallel chords has for nearly four years been published in the writer's work on "Stresses in Bridge and Roof Trusses."

Again, although Mr. Vautelet does not mention the fact, his results for shears do not give the maxima web stresses unless the two chords of the trusses are parallel. The writer believes that Mr. Henry W. Hodge, C.E. Student Institution of Civil Engineers, of the engineering office of the Phœnix Bridge Co., was one of the first, if not the first, to point out the fact that different positions of loading from those for parallel chords are required for chords not parallel, when maxima web stresses are sought.

The following investigation shows the effects of non-parallelism, and gives the positions of loading as well as the maxima web stresses themselves for the principal types of trusses.

Two principal cases occur in connection with types of structures ordinarily used in engineering practices. That one to be tested first is the case of the intersection of the chord sections, in any panel, lying below the inclined web member in the same panel; the other is the case of the intersection lying above the inclined web member.

Application of these principal cases to special features can easily be made after the general results are obtained.

Case I. *The intersection of chord sections below the inclined web member.*

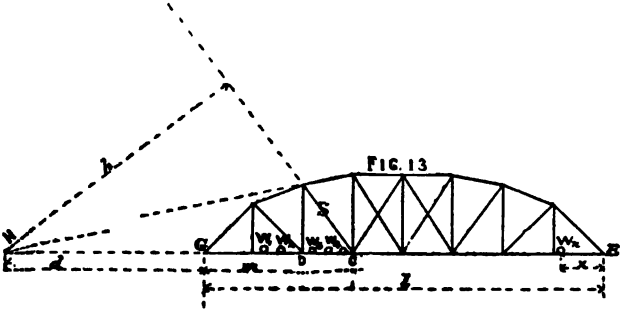


FIG. 13

Let l (*Fig.* 13.) be the length of span; d the distance from end of span to the point of intersection H of the chord sections in the panel in question; m the distance from the end of the span to the same panel whose length is p; S, the stress in the web member under consideration, and L its lever arm about H; a, b, c, etc., the distances separating W_1 from W_2, W_2 from W_3, etc., etc.; W_1, W_2, etc., the weights resting between G and D, and W_3, W_4, etc., the weights resting in the panel p, while W_n, distant x from E, is the last weight, resting on the span from C to toward E; b is the distance from D to the nearest weight W_3 The reaction at G is:—

$$R = W_1\left(\frac{a+b+c+\ldots+x}{l}\right) + W_2\left(\frac{b+c+\ldots+x}{l}\right) + etc\ldots W_n\frac{x}{l} \quad (1)$$

Taking moments about H:—

$$Sh = Rd - W_1\left(l+d-a-b-\ldots-x\right) - W_2\left(l+d-b-c-\ldots-x\right)$$

$$- etc. - \left(W_3\ \frac{p-b}{p}\right) + \left(W_4\ \frac{p-b-c}{p} + etc\right)\left(m+d\right)\ldots\ldots(2)$$

By moving the entire load the distance Δx toward G, remembering that

the change in the value of R will be $\Delta R = (W_1 + W_2 + \ldots\ldots + W_n)\frac{\Delta h}{l}$

the change in S h becomes:

$$\Delta S\ h = (W_1 + W_2 + \ldots\ldots + W_n)\frac{\Delta x}{l}d - \left(W_1 + W_2 + etc\right)\Delta x$$

$$- \left(W_3 + W_4 + etc,\right)\frac{\Delta x}{p}\left(m + d\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

For a maximum or minimum $\Delta S\ h = 0$, hence:—

$$W_1 + W_2 + \ldots\ldots + W_n = \frac{l}{d}\left(W^1 + W_2 + + etc.\right)$$

$$+ \left(W_3 + W_4 + etc\right)\frac{l(m+d)}{pd} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Bearing in mind that the first parenthesis in the second member of eq. (4) represents the load between the panel p and the left end of span, and that the second represents the load in panel p itself, it will be at once seen that, when the load extends from E to W, S is the maximum main stress, and that when it extends from G to W_4 (*i.e.*, to the weight farthest towards E), S is the maximum counter stress. Eq. (4), therefore, as it stands, gives the conditions for maximum main or counter stresses.

Eq. (4) is perfectly general in character, and covers all systems of loading whatever, but it may be put in special forms for convenient application in special cases.

Example (1) *Uniform Load.*

If the load is continuous or only partially so, and w is its intensity (*i.e.*, its amount per. lineal unit) at any point distant x from E, then its various concentrations W_1, W_2, W_3, etc., will be separated by $w\,dx$. If, further, the load is uniform and continuous, w is constant, and $W_1 + W_2 + \ldots\ldots .+ W_n = w\,x_1$, x_1 separating the length of uniform load on the bridge. In the same manner, if x_2 represent the length of uniform load from D towards G,

$(W_1 + W_2 + \text{etc.}) = w\,X_2$; and $(W_3 + W_4 + \text{etc.}) = w\,r\,p$; r being the fractional part of the panel p covered by the uniform load m

Equ. (4) then becomes:—

$$wx_1 = \frac{l}{d}\,wx_2 + wrpl\,\left(\frac{m+d}{pd}\right)$$

$$\text{Or, } x_1 = \frac{l}{d}\,x_2 + rl\left(\frac{m}{d} + 1\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

As with the general case so with equ. (5), it is so written as to give both maximum main and counter stresses.

If the load is placed for the greatest main stresses, $x_2 = 0$ while $x_1 = np + rp$; in which np is the length of loading from C towards E:—

$$np + rp = rl\left(\frac{m}{d} + 1\right) \text{ and } r = \frac{n\left(1 - \frac{l}{d}\right)}{\frac{l}{p}\left(\frac{m}{d} + 1\right) - 1} \quad \ldots\ldots(6)$$

If the load is placed for the greatest counter stress;

$$x_2 = \frac{d}{l}x_1 - dr\left(\frac{m}{d} + 1\right) \quad \ldots\ldots(7)$$

Or if there is no load between C and E, and if $np = x_2$ is the length of load from D towards G, Equ. (7) will become:—

$$n\left(1 - \frac{l}{d}\right) = p\frac{l}{p}\left(\frac{m}{d} + 1\right) \text{ and } r \therefore r = \frac{n\left(1 - \frac{l}{d}\right)}{\frac{l}{p}\left(\frac{m}{d} + 1\right) - 1} \quad \ldots\ldots(8)$$

Equ's (6) and (8) will enable the position of moving load to be at once computed without trial.

Example II. Loads at panel points only.

If loads are located at the panel points only, then W_1, W_2, W_3 etc., will be the panel loads, and a, b, c, etc., the panel lengths, and equal to each other in case those lengths are uniform; the parenthesis in eq. (2) multiplied by $(m + d)$ will also disappear. Substituting R from eq. (1) in eq. (2) with the last parenthesis dropped, there will result

$$Sh = W_1\left(a + b + c + \ldots\ldots + x\right)\left(\frac{d}{l} + 1\right)$$

$$+ W_2\left(b + c + \ldots + x\right)\left(\frac{d}{l} + 1\right) + \ldots etc. + W_3\left(e + \ldots + x\right)\frac{d}{l} + \ldots$$

$$+ W_n\frac{xd}{l} - \left(W_1 + W_2 + \ldots\ldots etc.\right)\left(l + d\right) \quad \ldots\ldots(9)$$

The last term of the second member represents the loads between G and D.

The position of loading for a maximum of S will, in the general case, be determined by trial, by ascertaining in what position the second group of positive quantities in the second member ceases to increase more rapidly (as the load progresses) than the negative difference between the first positive group and the negative last member.

This can only happen if the panel weights toward, or in the vicinity of W_n, are very heavy relatively to those toward, or in the vicinity of W_1. If the heavy panel loads are W_1 and those near it, *i.e., if the heaviest panel loads are at the head of the train*, the following analysis shews the positions for maxima stresses, in which, it is to be observed, W_1 is the near panel load for counter stresses.

Since $(a+b+c+\ldots\ldots+x)\ (d+l) < (d+l)\ l$, and

$$\therefore \left(a+b+c+\ldots\ldots+x\right)\left(\frac{d}{l}+1\right) < \left(d+l\right), \text{ it is clear that}$$

for maxima main stresses the loads must extend from the farther end of the span to the main member in position.

Since the counter shear is negative, *i.e.*, opposite in sign to the main shear, the negative portion of the second member of Equ. (9) must be as large as possible for the maximum counter shear and the positive portion as small as possible. Hence the portion

$W_3\ (e+\ldots\ldots+x)\ \frac{d}{l} + \ldots\ldots + W_n \frac{xd}{l}$ must be omitted and the load W_1 placed at the panel point nearest the end G, *i.e., the load must cover that portion, of the span between the counter and the nearest end of the span, for the maxima counter stresses.*

Hence for main web stresses under the assumed conditions :—

$$S=\frac{1}{h}\left\{W_1\left(a+b+c+\ldots\ldots+x\right)+W_2\left(b+c+\ldots\ldots+x\right)\right.$$
$$\left.+\ldots\ldots W_n x\right\}\frac{d}{l} \qquad \ldots\ldots (10)$$

and for counter web stresses :—

$$S=\frac{1}{h}\left\{W_1(a+b+\ldots+x)+W_2(b+c+\ldots+x)+\ldots.etc\right\}\left(\frac{d}{l}+1\right)$$
$$-(W_1+W_2+\ldots\ldots etc)\frac{l+d}{h} \qquad \ldots\ldots (11)$$

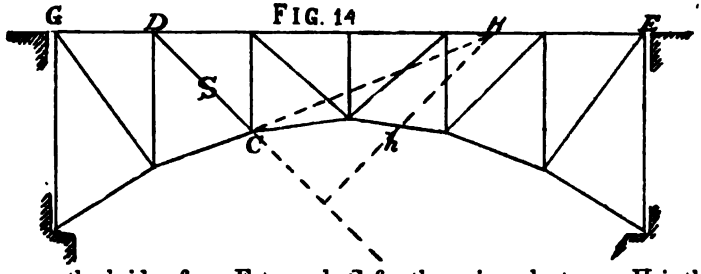
The conditions on which Equ's. (10) and (11) are based are precisely the same as if the chords are parallel. In the latter case $d=\infty$, $h=\infty$

$$\frac{d}{hl}=\frac{\sec a}{l},\ \frac{1}{h}=o \text{ and } \frac{l+d}{h}=\sec a$$

Case II. *The intersection of chord sections above the inclined web member.*

This case is illustrated by Fig. 14, in which let the stress S in the member DC be under consideration. The moving load is supposed to

FIG. 14



pass on the bridge from E towards G for the main web stress; H is the point of intersection of the chord sections, while GH and GD are the distances d and m respectively. All other notations remain precisely as in the previous case. The reaction, R, under G is given by Equ. (1), Bearing in mind that distance DH is now $(d—m)$ and taking moments about H there will result :—

$$Sh = Rd - W_1(d - l + a + b + \ldots\ldots + x) - W_2(d + l + b + c + \ldots + x)$$
$$- etc. - (W_3\frac{p-b}{p} + W_4\frac{p-b-c}{p} + etc.)(d-m) \ldots 12$$

Precisely the same operation which follows Equ. (2), shows that the desired condition for a maximum is given by the following equations :—

$$W_1 + W_2 + W_3 + \ldots\ldots + W_n = \frac{l}{d}(W_1 + W_2 + etc)$$
$$+ (W_3 + W_4 + etc)\frac{l(d-m)}{pd} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

The different positions of Equ. (13) evidently represent exactly the same loads as the same portions of Eq. (4). It is also clear from the same considerations that if the loads extend from E to W_1, Equ. (13) gives the position for a maximum main stress, and a maximum counter stress if they read from G to W_4 (*i.e.*, to the weight farthest towards E).

Equ. (13) like Equ. (4) applies to any system of loads whatever, and can be applied to special cases in the same manner.

Ex. III. Uniform Load.

By using the same notation and the same process of reasoning as in Ex. 1, Equ. (13) takes the form for the greatest main stress :—

$$x_1 = \frac{l}{d}x_2 + rl\left(1 - \frac{m}{d}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

or for the greatest counter stress :—

$$x_2 = \frac{d}{l}x_1 - dr\left(1 - \frac{m}{d}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

Ex. IV. Loads at panel points only.

Let it be first supposed that d is less than l, *i.e.*, $d < l$.

The same general considerations that were given in Ex. II. applied to Equ. (12) will cause it to take the form :—

$$Sh = -W_1(a+b+c+\ldots\ldots+x)\left(1-\frac{d}{l}\right)$$

$$-W_2\,(b+c+\ldots\ldots+x)\left(1-\frac{d}{l}\right)-\ldots\ldots-etc.$$

$$+W_3(c+\ldots\ldots+x)\,\frac{d}{l}+etc,+(W_1+W_2+etc)\,(l-d)\ldots(16)$$

Since $(a+b+c+x)\,(l-d)<l(l-d)$,

$$\therefore(a+b+c+\ldots\ldots+x)\left(1-\frac{d}{l}\right)<(l-d).$$

Therefore in order that the second member of Equ. (16) should have its greatest *positive* value, *the loads must be at all the panel points.* Equ. (16) also shows that in the case now under consideration there can be no reversal of stresses in any web member. In the inclined member S, the stress will always be tension and always compression in the vertical member passing through its upper extremity. The positions for the actual maxima stresses can be found by trial only, as they will depend on the amount of the panel loads and their location relatively to each other.

Let it next be supposed that d is greater than l, *i.e.*, $d > l$.

In this case $(l-d)$ becomes negative, or $(d-l)$ positive, and the conditions for maxima values are the same as those fixed for eq. (9); hence they need no further attention.

A remaining example with the intersection of chord sections, *below the inclined web member*, and between it and the end of the span, can be treated in precisely the same general manner as the preceding. The moving load between G and D would lie, in the general case, partially on one side of the point of intersection and partially on the other. This form of truss, however, has little or no technical interest and needs no further attention.

The preceding treatment applies to any forms of truss, whether deck or through, with one chord horizontal. In the application of any particular formula it is only necessary that the point of intersection of the chord sections shall be located according to the condition on which the formula is based.

The treatment also applies to any system of web members, whether they are all inclined at different angles, to a vertical line or at equal

angles, or, again, if, as in the figures a part of them are vertical. It is only to be borne in mind that two web members intersecting in the unloaded chord take their greatest stresses together, only *when that chord does not change its direction at that point of intersection.*

In case that direction does change, the value of "d" will be different for the two members, although "m" will remain the same.

Short methods of computation, well known in every engineering office, make practical applications of preceding formulæ easy and rapid.

Prof. Bovey. In a paper recently read by the speaker before the Royal Society, it was shewn that when a number of isolated loads travel at fixed distances apart, over a girder AB :—

(a) The shearing force at any given point for a given distribution of the loads will be greater or less than the shearing force at the same point when the loads have moved a distance x from B towards A according as,

$$T - L \gtrless R_s - R_p + \frac{x}{l}(W_n - L) \qquad (A)$$

(b) and the bending moment at the point for the first distribution will be greater or less than the bending moment for the second distribution, according as

$$z(L - T + R_s - R_p) + l(R_q - R_s)$$
$$+ x(W_r - L + T) \gtrless \frac{x}{l}(l - z)(W_n - L) \qquad (B)$$

In the above relations,

L = total load which leaves the girder

T = " " transferred from one side of the point to the other.

R_p, R_s, R_q are the reactions at the support A, due respectively to the weight which leaves the girder, the new weight which advances on the girder, and the weight transferred from one side of the point to the other.

z = distance of given point from B.

l = length of girder.

$W_n = w_1 + w_2 + \ldots + w_n$

= total weight initially on girder.

When no weights leave or advance upon the girder

$\therefore$ R_o R_p and L are severally *nil*, so that (A) becomes

$$\frac{T}{x} \gtrless \frac{W_n}{l} \qquad (C)$$

i.e., $\dfrac{\text{weight transferred}}{\text{distance of transfer}} \gtrless \dfrac{\text{total weight}}{\text{span}}$

which agrees with the result given by the author,
and (B) becomes

$$-z.T. + l\,R_q + x\,(W_r + T) \gtrless \frac{x}{l}(l-z)\,W_n,\ W_r \text{ being}$$

the sum of the first r weights.

If the given point initially coincides with the r^{th} weight, and if x is equal to the interval between the r^{th} and $(r+1)^{th}$ weights, the last expression easily reduces to

$$\frac{W_r}{l-a_r} \gtrless \frac{W_n}{l} \qquad (D)$$

where $l-a_r$ = distance between r^{th} weight and A. This last expression also agrees with the result given by the author as the condition for max. bending moments.

It is necessary to bear in mind that (C) and (D) are only special cases of the general problem, and are also only true for trusses with horizontal chords.

If the upper chord is not horizontal, consider a diagonal between the r^{th} and $(r+1)^{th}$ weights.

Let the corresponding panel length of the upper chord produced meet the horizontal chord produced in the point C.

Let C A $=h$

" p be the perpendicular from C upon the diagonal in question

" R_1, R_2 be the reactions at A due to the 1st. and 2nd. distributions, respectively

" D_1, D_2 be the corresponding diagonal stresses.

Suppose, for simplicity, that no weights either leave or advance upon the girder.

$$\therefore R_1.\ l = w_1.\ a_1 + w_2\,a_2 + \ldots + w_n.\ a_n$$

$$D_1.\ p = R_1.\ h - w_1(h+l-a_1) - w_2(h+l-a_2) \ldots - w_r(h+l-a_r)$$

$$R_2.\ l = w_1\,(a_1+x) + w_2(a_2+x) + \ldots\ldots + w_n(a_n+x)$$

$$D_2.\ p = R_2.\ h - w_1(h+l-a_1-x) - w_2(h+l-a_2-x) - \ldots\ldots$$
$$- w_r(h+l-a_r-x) - w_{r+1}(h+l-a_{r+1}-x) - \ldots\ldots\ldots$$
$$- w_{r+q}(h+l-a_{r+q}-x)$$

Hence, $D_1 \gtrless D_2$. according as,

$$x\,(w_1+w_2+\ldots+w_r+w_{r+1}+\ldots+w_{r+q})+w_{r+1}(h+l-a_{r+1})+\ldots\ldots$$
$$+w_{r+q}\,(h+l-a_{r+q}) \gtrless (R_2-R_1)h$$
$$\text{or } x.\ (W_r+T)+R'_q.\ (l+h) \gtrless W_n\, x\,\frac{h}{l} \qquad (E)$$

where $R'_q\,(l+h)$ is equal to the algebraic sum of the moments of the "weights transferred", with respect to C.

If no weights are transferred, the preceeding relation reduces to,

$$\frac{W_r}{h} \gtrless \frac{W_n}{l}$$

Relation E corresponds to that given by Prof. Burr.

The speaker fully agrees with Professor Burr in his opinion as to the uselessness of the extremely nice calculations now so frequently required by specified arbitrary concentrations, and gave utterance to this opinion before this Society during the early days of its existence. The calculations certainly provide useful exercises for students at college, but in practice at least equally approximate results may be arrived at by the much simpler assumption of a uniformly distributed load with a concentrated excess in the front, or in any other specified position. The varying types of locomotive, with their constantly increasing weight, render nugatory, except for *one* particular assumption, all stress calculations based upon arbitrary weight concentrations.

Mr. Dawson. The speaker had not the advantage of hearing Mr. Vautelet's paper read at the previous meeting, but understands from reading it that the main point for discussion is whether it is better in bridge calculations to take the individual wheel loads or to assume an equivalent distributed load.

It is pretty generally admitted, so far as the truss as a whole is concerned, especially on long spans, that the distributed load is quite sufficient for all practical purposes.

The difficulty, however, in taking one distributed load is that on special parts of the bridge and in many details the strain is considerably in excess of anything that could be figured out from the distributed load.

With regard to the practice of calculating bridges with such great accuracy; under older practice, as on the continent of Europe, there was a redundance of material put into bridges to meet special cases, such, for example, as the passage of individual wheels.

On the other hand, in figuring down to rigid economy and strict accuracy, there is the great advantage of getting a lighter bridge; and American methods of calculation, design and detail have specially contributed towards the rapid erection of bridges with the greatest economy in material, which are important features on this continent, when one considers the great distance material has often to be transported, together with the difficulty of transportation and the reduced time occupied in erection.

These are the main reasons for the American design and the close calculations it requires.

The limit, however, has been reached both in reference to accuracy of calculation and economy of material; and in reaching the limit it is quite obvious that a number of points, such as were mentioned in the paper, were not taken into account, and were probably not worth considering; such items, for example, as extra stiffness given to posts by rivetted attachment to the floor beam, the impact, and other details of a similar nature, which, as a rule, are never gone into.

In these circumstances the question arises, whether it would not be sufficient to take a more general load instead of taking the wheels in detail. The advantage of doing so in saving tedious calculation is evident, as each position of the wheels involves the complete calculation of the bridge, unless the insight is acquired by practice which enables the cases yielding maximum values, and the members upon which they come, to be selected in advance. On the other hand if distributed loads alone are taken, a great deal is left out in regard to the strains coming upon details. It would be necessary to assume a very low value for rivet shear, and allow the excess of strain actually occurring to trench on the margin of safety.

The best way to obviate both difficulties would be to take a distributed load for the truss as a whole, and to specify also the wheel loads for the calculation of the attachments and details, and for these only. A distributed load to be equivalent to the actual loading must increase as the span diminishes; and it would therefore be necessary to specify a series of such loads for spans of different lengths down to the shortest girder spans. It would also be necessary to specify more than one engine to obtain the actual maximum strains in the details, as in practice a lighter engine may cause a greater strain on some of the individual parts of a bridge. For example, a 48 ton engine may have drivers on which there are 16,000 lbs. each, while in a consolidation engine with more wheels, the load may not exceed 12,000 lbs. on any one driver; and these engines will affect the details of attachment differently.

It is to some extent a question between specification and practical calculations. To specify the engine wheels and the train load following is a comparatively simple matter; it is done once for all, and leaves the onus of the work to the calculations. But without doubt the practical calculation is the consideration which ought to overweigh the other, and the practical result would be fairly the same in either case.

The question, therefore, is one of reducing the labor of calculations and arriving at a reasonable result. It would make the specification a little more detailed perhaps, but the advantage gained would be quite worth the difference.

Mr. Vautelet. It was not the purpose of the author of the paper to find a formula which would give the same results as the calculations based upon the assumption of one or two engines followed by a train, and that for several reasons:

1. It is probable that, during the life of the bridge, there never will be on it such a load as the one specified.

2. If such a load as that specified were standing on the bridge, the actual stresses would not be those found by the most accurate calculations in use.

3. Even if they were the same, the stresses produced by the given load when moving would be entirely different.

Hence the elaborate calculations made in most cases have no object. Our knowledge of actual strains under a moving load is very small indeed. The bridges already built according to static calculations have stood; and as long as nothing better is known, more attention should be given to design and less to calculations, as direct experience shews that the former admits of much improvement.

In the formulæ given the coefficients were taken as follows: Over 105 feet, which is about the length occupied by two consolidation engines, the total wheel load was simply divided by 105, the result being 3730. For spans between 21 and 105, 21 feet was assumed to be about the wheel base of one engine, giving 4600 per foot, and a value of 3240 was calculated to make it correspond with 3730 of the first formula. There is nothing scientific about the process, and the application is easy enough. It may be added that the author has made the calculations for a large number of bridges, taking the wheel load and the formula, and the results are practically the same. As the results are known to be merely approximate, it cannot be supposed that a difference of even 2 per cent. can be of any importance.

The author was pleased to observe that Prof. Burr was advocating

some other method of calculations, as he was one amongst the first to put wheel loads in practical use. The method he now advocates, however, seems to have objections. Why a single concentration at the head or in some other position, with a simple uniform load? Where, in the case of chord calculations, is that load to be located? Does it not seem strange to have that heavy weight located somewhere on a bridge when there is nothing similar in a train? So far a distributed load has been taken for the train, and why not take one for the engine? This would provide a load that would not be the actual load, but that would have the merit of being a reasonable assumption. Would it not be the best way for young engineers who intend to follow the profession to see bridges built at the shops and then erected, and more especially to inspect carefully old structures?

When subsequently engaged in designing and making rougher calculations, they might put only 10 erection rivets where a first-class calculator would shew 12 to be needed by specifications. But in their plan it would be possible to drive the ten rivets and get a good job, whereas out of the twelve rivets only 6 or 8 might possibly be driven. In fine, a bridge is not a good bridge because it complies with a specification as to strains. A bridge is good because it has been well designed and well built with fairly good material, because it is stiff, and because there is not too much difference between strains due to live and dead load. If with those conditions 60,000 pounds steel happens to be strained to 18,000 pounds, the bridge will not be any the worse for it. Most of the failures are due to bad design, and many bridges are much over-strained though they still stand. In former times there was too much rule of thumb method in bridge calculations; but now there seems to be too much calculation, or at least calculation of the wrong kind, and it would appear that in bridge designing, a little more experience and a little less theory might be desirable.

Thursday, 24th October.

K. W. BLACKWELL, Member of Council, in the Chair.

Paper No. 33.

DESIGN AND CONSTRUCTION OF THE AVON BRIDGE.

By R. F. UNIACKE, M.Can.Soc.C.E.

The problem of renewing the old toll bridge at Windsor, known as the Avon Bridge, had for years been looked upon as a perplexing and costly undertaking, and it was not until the early part of 1886 that actual steps were taken by the Government of Nova Scotia to take over the old bridge, open it free to the public, and make provision for its renewal, when in the interests of the public safety this should become necessary.

The old bridge was built in the year 1836, and consisted of five spans, varying in length from 147 to 162 feet in clear, supported by piers and abutments of close faced cribwork with cribwork approaches. The height of piers was from 45 to 50 feet. Ordinary tides rise 27 feet, spring tides 34 feet. The trusses were Town's wooden lattice, double, with double chords top and bottom. The whole of the trusses were built of 3" planking, and housed in. They had been supplemented by wooden arches springing from about 6 feet below the floor; an additional pier had also been built under the centre of one of the spans. The structure had settled and warped considerably, in some places as much as four feet, and all indications pointed to the fact that it would soon become necessary to take steps for its renewal.

The structure having been purchased by the Provincial Government from the stock company which had hitherto owned it, was at once declared free of toll to the public for ordinary traffic. Some repairs were put upon it, extra vigilance being exercised to prevent heavy and continuous traffic, and with these precautions the public were allowed the use of it, until such a time as the progress of the new work would render it necessary to close it altogether.

The question of renewing the bridge having been decided upon, it was next to be determined what style of structure should be erected.

Besides the plan selected, two designs were submitted. One was for four spans of iron 200 feet each between end pins, supported by piers and abutments of close-faced cribwork filled with concrete; roadway

18 feet in clear with two footways 5 feet each; estimated cost $56,000. The second design was for four spans of Howe truss of wood, 160 feet each, and two smaller spans of wood, 120 feet and 50 feet respectively, piers to be of close-faced cribwork filled with stone, estimated cost $36,000.

The first would have made a strong and handsome structure, but the cost was considered excessive. The plan for a structure altogether of wood was strongly advocated by adherents of the old system, who argued that since the old wooden bridge had stood so long, a similar structure would answer all requirements. This view at first sight seemed reasonable enough; but when we consider the fact that the bridge had in its lifetime undergone a series of repairs and additions, and that such costly repairs together with the first cost of the bridge would go for naught in considering its reconstruction, it was not thought desirable in view of the experience of the past to project a similar experience into the future.

Before taking up and describing the supplementary and adopted plan, it may be as well to state some of the reasons why a masonry substructure did not enter into the calculations. The experience gained in this Province, from bridges built across tidal estuaries of the Bay of Fundy, goes to shew that masonry structures built in these places have invariably proved failures, whereas old bridges that have been built of cribwork, as far as the piers are concerned, have stood firm and sound, without appearance of decay below high water mark, for half a century. A most striking example of the failure of masonry is close to this bridge in the Windsor and Annapolis Railway Bridge, crossing the Avon River a few hundred feet up stream. This is a rivetted iron lattice bridge of the English type, with river spans 166 feet centre to centre of piers. The piers were completed in the year 1869, and are of regular coursed ashlar masonry. Since that time several thousand dollars have been expended on them in repairs. The face stones had been connected by iron dogs or clamps, which had not prevented the destructive process which was threatening the stability of the structure; the effect of tides and frost each year became more apparent, the piers became cracked, these cracks seeming to extend completely through them so that they were considered unsafe, and were condemned by the Provincial Government. The Railway Company has surrounded these piers with close-faced cribwork, leaving a clear space of about 3 feet all round, which space was filled with concrete, and iron rods passed through the piers outside to outside, making a permanent and substantial work, though somewhat detracting from the appearance of the structure.

Precisely the same course was adopted on the Intercolonial Railway bridge at Sackville, N.B., and extensive repairs and renewals have been made on the piers of the railway bridge across the Shubenacadie, both tidal rivers of the Bay of Fundy.

These and other examples, together with the excessive cost, precluded the adoption of masonry.

The form of the structure as adopted and built may be described as follows: Beginning at the Windsor side was a small span of iron, 50 feet centre to centre of end pins, then four spans of 159 feet each, and a shore span on the Falmouth side of 110 feet. There were five piers placed 162 feet centre to centre, each pier consisting of two cylindrical columns of 5 feet inside diameter 19′ 4″ apart centre to centre, built of steel plates $\frac{3}{8}$″ in thickness, the joints both vertical and horizontal butted together and connected by steel bands $4\frac{1}{2}$″ × $\frac{3}{8}$″ rivetted on the outside. The bottom of each column was provided with a flange turning outwards, formed by bending a 3″ × 4″ angle iron and rivetting it on. This bottom flange in each instance rested upon the bed rock. The distance from a little above low water to the underside of the cap was divided into three spaces by four horizontal struts, each strut consisting of two laced channels abutting against the columns, and secured by connecting plates; pins were placed in the ends of each strut, and all connected with $1\frac{3}{4}$″ round iron rods with turnbuckle adjustment. Each pair of columns was enclosed up to 2 feet above low water with a cribwork of square timber 20′ × 40′ outside measurement. Spaces 8′ × 8′ were left in the cribwork, where the columns would come, and these spaces together with the cylinders themselves were filled to the top with concrete; the remaining voids in the cribs were filled with stone. Each column was capped by a circular plate and an ornamental casting *cyma recta*. Two 12″ rolled beams, 60 lbs. per foot each, extended across the columns secured to the caps, and upon these beams rested the bed plates of the trusses.

To protect the sway bracing against the heavy ice floes, a system of sheathing was built between the columns, enclosing the rods and struts on each side from high water down with 4″ plank, placed vertically, and bolted through and through, wooden struts being placed at intervals between them to keep the planking the right distance apart. As a further precaution, extra cribwork with stone filling was built up, the same section as before, to the second horizontal strut, or 26 feet below the floor of the bridge.

The height of each pair of columns from finished floor of bridge to surface of rock foundation as built was:—

Pier No.	1	47.36′
"	2	59.84′
"	3	49.65′
"	4	53.94′
"	5	55.63′

The columns varied slightly in height, that given being the average height of each pair.

The cribs were built on shore, and sufficient ballast placed in them to partially submerge them. They were then towed to their place, and all the voids except those reserved for the columns were filled with stone at time of low water.

The bed rock extends across the stream; in some places it is bare, at others it is covered with from two to six feet of mud and silt. Means had been provided for removing this deposit from within the cribs, but this was not found necessary, for when the cribs were once placed in position, the increased tidal current caused by contracting the waterway completely scoured this loose material out, leaving the rock bare, and any loose stones or detached boulders were removed by grapnels.

As an additional precaution against any tendency of the cylinders to slide on the rock, it was determined to secure them by iron dowels. Nine of these were used in each column. A rough floor was placed across the crib, and the exact position of each cylinder marked upon it; auger holes were bored as guides, and the rods of two inch round iron tempered at the end, and fashioned to a rock drill point, were jumped into place. No difficulty was found in thus drilling three feet into the rock, leaving about five feet projecting.

At this stage preparations were made for lowering the bottom sections into place. The lengths of these sections as shipped, vary from $9\frac{1}{2}$ to $23\frac{1}{2}$ feet. The roof and side covering had by this time been removed from the old bridge, and overhead braces were secured strong enough to take the weight of sections, which were lowered into place through the floor by block and tackle. A wooden cross-head was fixed to the top of each section, the centre marked on it, and the cylinder accurately centred by means of a suspended plumb bob. The section was secured by wooden shores against the inside of the crib, and everything was now ready for the concrete filling. The materials for this were brought alongside in a scow. The mode of laying the concrete as practised here, in from five to twelve feet of running water, is a somewhat novel experiment, and the success which attended it in this case, will lead to its adoption in other instances in this province.

This point has been referred to by Mr. Murphy in his paper on Concrete Structures, read before this Society; * but a more detailed account of it will perhaps be in keeping with the subject of this paper. Coarse brown paper bags, well stiffened with glucose, of a capacity of two cubic feet, were employed. A small wooden tray, suspended on trunnions at the end of a pole, was used, and could be tipped at any position by the workman guiding the pole by a cord attached to the back of the tray. The bag was placed upon the tray, and about one cubic foot of concrete placed in it, the superfluous paper being roughly folded down. The whole was raised from above by a rope attached to the handle, guided into place by a man standing on a plank placed across the top of section, and tipped at the proper time. This operation was repeated very quickly, the paper dissolving and breaking up almost as soon as the bottom was reached, allowing the concrete to flow into any cavities or irregularities in the rock under the cylinder, and forming a level bed of concrete. This operation was continued until the cylinders were filled to within a foot or two of the bottom lateral strut, and the voids around them filled to the top of cribs.

As soon as a pair of bottom sections were secured in place, levels were taken on the top of them, and the exact height from the top of each to finished floor was at once sent to the Dominion Bridge Co., contractors for the iron work, thus enabling them to send the proper length of sections to complete the columns. The same operation was performed for each of the foundations, the concrete gang being on hand as soon as the iron men had placed the bottom sections in position.

Before the cribs were all set, the Falmouth span at the shore end caught fire and soon dropped into the river, the trusses breaking off at the pier, and the burning mass floating downstream with the tide. Up to this time the public had the use of the old bridge. Our located points for pier No. 5 were of course gone, and a quick and ready means had to be adopted for setting these cylinders in proper position. This was effectually done by means of steel wires lined in position over centre of each cylinder. Two *plus* points were measured as far as convenient on the old floor; the distance to the abutment was about 160 feet, and we had 51 feet to centre of new pier. These distances were first carefully laid out on the old floor, and the points fixed on the wire which was stretched clear off the floor with a plummet attached at this point, and

* Concrete as a Substitute for Masonry in Bridge Work, by M. Murphy, Transactions. Vol. II., Page 79, Feby., 1888.

giving the wire the same curve it would have in its proper position. The wires were next drawn across the opening, with plummet attached, brought to the same sag and made fast. This was done on a calm night, and proved an accurate means of setting these columns.

The cribs for piers Nos. 4 and 5 were built larger than the rest, being 51 × 30 feet outside measurement. Shears had been erected on the last crib for handling the sections. Through some accidental cause a portion of the ballast had fallen into the voids of this crib reserved for the columns and it became necessary to employ a diving crew to remove them. With this exception, the operation of setting the bottom sections as previously described was performed for each of the piers.

The time of setting these sections was as follows:

Pier No.	1,	July	19th,	1887
"	2,	"	25th,	"
"	3,	"	28th,	"
"	4,	Aug.	9th,	"
"	5,	"	19th,	"

Two periods of low tide were generally sufficient for setting these sections. The first tide was sufficient for a pair of them to be lowered, and they were secured and centred at the next.

The foundations by this time were all ready for the iron men to proceed with their work of completing the columns and connecting the sway bracing; but owing to unfortunate delays caused by unforeseen difficulties, the remainder of the iron did not arrive on the ground until late in the fall. The process of building on the sections proceeded with energy; the sway bracing was connected, and concrete filling followed on as fast as each section was rivetted. Cold weather suddenly came, and with it a run of ice in the river. Piers Nos. 1, 2 and 3 had been completed and filled with concrete up to high water, pier No. 4 partially finished, but pier No. 5 had to be abandoned without any bracing or concrete filling, above low water. Urgent efforts were made to get these finished, but with the river now almost blocked with floating ice, the men's lives were in danger, and the work had to be left, not, however, till the 50 feet span had been swung, and two sets of false work for the next span had been carried away. Attempts to get the sheathing in place failed, but some additional protection of round timber had been built around the cylinders.

The columns were now left in a seemingly precarious condition, without the trusses to stiffen them longitudinally, the cross bracing exposed to heavy ice floes, which could strike them obliquely with the force of

the rushing tide, and some of them only partially filled with concrete, or not at all.

The winter months passed, and the proverbial oldest inhabitant failed to recollect larger or more continuous floes of heavy ice than the Avon river experienced during that time. When spring came, it was found that pier No. 4 had experienced some dents above the concrete filling, and one of the tie rods was broken. Pier No. 5, which had no bracing or concrete filling, was partially demolished, the rest stood firm and perfectly true. This might fairly be considered a pretty severe test, and a sufficient answer to much adverse criticism on the adaptability of such a structure for the Avon River.

Operations were resumed in the month of May, and prosecuted to completion. The injuries to the columns had been repaired, the missing plates replaced and filled to the top with concrete. The work proceeded with rapidity, and the last span was swung in the first week in July. Soon afterwards the bridge was opened for traffic.

The superstructure is the ordinary type of American pin-connected Pratt truss with an ornamental iron lattice hand railing on each side. The specifications were the same as generally adopted under the Nova Scotia Bridge Act for iron bridges, with special clauses and modifications to suit this particular case, and as they would present nothing new it will not be necessary to reproduce them here, beyond a few of the principal requirements.

One span 50 feet between end pins.
Number of panels 5.
Depth of truss, 8 feet.
Four spans 159 feet each between end pins.
Number of panels, 10.
Depth of trusses, 22 feet.
One span 110 feet between end pins.
Number of panels, 7.
Depth of truss, 22 feet.
Roadway throughout 18 feet in clear.
No footways.

Rolling load 1,350 lbs. per lineal foot, or 75 lbs. per square foot of roadway.

Ultimate tensile strength of iron at least 50,000 lbs. per square inch, an elastic limit not less than 26,000 lbs. per square inch, and a minimum elongation of 20 per cent. in 8 inches. Tensile strain produced in any member not to exceed 10,000 lbs. per square inch. Working

strain reduced on counters, hip verticals and beam hangers. Working compressive strain not to exceed 8,000 lbs. per square inch reduced by formula.

The cylinders were to be put together in sections of not greater length than 8 feet of $\frac{3}{8}$-in boiler plate hot rivetted, no screw bolts to be allowed in connecting the sections. On top of each pair of cylinders there were to be two rolled I beams, 12 inches in depth, 60 lbs. per foot each, with plates and stiffening T's to support trusses.

Considerable work was done on the approaches. The old abutment on the Windsor side was cut down to the foundation, and rebuilt. The floor in the approaches is supported by trestles resting on the old work at about high water level, and has a grade of 1 in 20.

The iron superstructure, together with the columns, was contract work, and was built by the Dominion Bridge Co., Engineers and Contractors, Montreal. The preparation of the found tions, cribwork, concrete filling, together with the work on the approaches, was all performed by day work, under Government superintendence.

Supplying material, such as sand, gravel, stone and timber, was generally let by contract, the contractor delivering the material at the bridge site as required.

A contract was also let for building additional cribwork around the cylinders up to within 26 feet of floor.

TOTAL COST OF WORK.

Erection of iron superstructure and columns.....	$32190
Substructure (days work).....	16395
Sheathing cribs and removing old piers (contract)	1760
	$50345

In looking at the cost of this work, it must be remembered that the circumstances here were anything but favorable to making a good showing with a crew of men in a short time. Men were at their post night and day, whenever the tide permitted, but could not work more than three hours at the most before having to make everything fast, and get ashore when the flood tide came. High wages had to be paid, as otherwise men could not be induced to work broken time in the wet and mud. Experienced foremen were employed, who ever kept a sharp look out for the safety of the men, as well as to see that each performed his full share of the work in a skilful and workmanlike manner, and it is a happy feature, that although the work was prosecuted at all hours

of the day and night, in a dangerous locality, especially when the cold weather set in, not an accident or fatality occurred.

The bridge as now completed, is in general appearance, such as to satisfy the most sceptical, and is, to the casual observer, the most elegant structure of the kind in this province. To the eye of the engineer it is bold and strong, each detail being designed to add strength where it is most needed. The columns have a graceful and finished appearance, the workmanship is all that can be desired, and standing side by side with the English lattice railway bridge, the two bridges present striking examples of the European and American practice.

From the drawings accompanying this paper Plate XII has been prepared.

DISCUSSION.

Mr. M. J. Butler.

The author deserves the thanks of the members of the Society, for presenting an interesting description of a class of work that will be of more common occurrence as the country grows older and richer, viz. the substitution of steel and iron for wood. The building of permanent work in the place of temporary structures will no doubt follow rapidly now that iron and steel of excellent quality are being produced cheaply, whereas, with the decrease in quantity, the price of timber keeps steadily increasing.

The Town Lattice Bridge, when roofed over, was an excellent type of wooden bridge and gave great satisfaction. There is one of 80 feet span at Napanee, Ontario, which was built in 1840, and is still in good order, the timber being perfectly sound.

The type of pier selected for the Avon Bridge is one very much used in the Western States, where, owing to deep mud, it is often difficult to get good foundations, the practice being to drive piles and fill in with concrete. Of course the difficulty of getting good stone has a great deal to do with the adoption of iron and concrete piers.

It would seem, however, in the case under consideration, that it would be better to have had each pier in one piece, with ice breakers at each end in the shape of cutwaters, similar in form to those adopted for the pier of the New Hawksbury Bridge in New South Wales. The cost would have been very nearly the same, while there is no doubt that the single pier would be stronger and safer.

It seems to the writer a mistake to build such an important bridge, on a specification of 75 lbs. to the square foot of roadway, for the following reasons:—

(1) All bridges are liable to the passage of heavy traction engines, concentrating from four to eight tons on two pair of wheels, seven feet centre to centre, to the passage of road rollers of the Aveling & Porter type, which weigh from ten to twelve tons, or to exceptionally heavy loads of machinery, stone, etc.

(2) The items that go to make up the cost of a bridge may be roughly divided as follows:—

a. Raw Material, rolled plate iron	55	per cent.
b. Work on same in the shop	15	"
c. Transportation	3	"
d. False Works and erection	12	"
e. Profit and Administration	15	"

Of the above (*a*) would be affected by providing for a greater load, (*b*) scarcely at all, (*c*) to a slight extent, (*d*) not at all, (*e*) probably not at all if competition is close.

To provide for 100 lbs. per square foot of roadway, and design the trusses accordingly, next to calculate the floor beams, hangers, etc., on the assumption that a road roller is to pass over them, would probably have added about 10 per cent. to the cost of the superstructure, but would have given a bridge that would, in all likelihood, have lasted forever, if painted at intervals.

Mr. E. A. Hoare. With reference to the cracks which threatened the destruction of the piers in the Windsor and Annapolis Railway bridge and other bridges over tidal rivers of the Bay of Fundy, can the author state if those cracks were confined to the cement joints only, or if they extended through stone and cement alike? And will the author also state the nature of the stone used in the localities mentioned? Did the stonework shew signs of decomposition and general disintegration as well as fracture? As the incomplete piers were subjected to such a severe winter's test as described, and that without shewing any serious signs of destruction, it would be interesting to know the approximate thickness of the ice which formed at the time mentioned, and its velocity of flow.

Mr. Dennison. Why is it that the stone piers seemed to fail more in this particular river than, for instance, in the St. Lawrence, or any other river subjected to ice floes? Would the result be the same if iron were used? Was the timber protected by creosoting or otherwise?

Mr. Blackwell. Mr. Blackwell imagined the selection of stone might be the cause of the trouble. Besides, stone absorbed water, and the action of the salt in the tidal rivers of Nova Scotia was terribly severe on bridges. There did not appear to be any iron exposed to the action of the salt water in this bridge.

Mr. Irwin. The author will no doubt reply to the questions put by Mr. Hoare. It would be interesting also to know whether the water was very salt. From the paper there appeared to be a large amount of cross-bracing, etc. Perhaps the cracks in the stones were caused by the scouring round.

Mr. Duggan. The fact that the piers were still standing showed then the water was not very salt. The teredo, however, was very prevalent in the locality.

Mr. Dennison. The two columns were referred to as being cased in brick work and filled in with cement.

Mr. Blackwell. Steel $\frac{3}{8}$" thick would not stand the chemical action of the salt water. Perhaps he did not understand the drawing correctly, but it seemed to him the columns were not exposed to the action of the water. The columns were between high and low water mark. The crib work extended to above low water mark. He thought $\frac{3}{8}$" steel would not stand long in such a position. If any one from the United States was present, it would be interesting to have some information about these tidal rivers, in some of which there was a tide of from 25 to 40 ft.

Mr. Whited. Mr. Whited said it was to be regretted that more information was not forthcoming. The superstructure was built by the Dominion Bridge Co. in Toronto. The columns were about as simple as they could be made, and were correctly described. They were made of $\frac{3}{8}$" steel plate, and as the author gave no details whatever of the iron work except a few extracts from the specification, there was little chance for discussion on that subject, as it seemed hardly correct to bring in points altogether foreign to the paper.

Mr. Blackwell. Mr. Blackwell said the question of stone was spoken of. The piers of other bridges made of stone had failed, which had led to the adoption of the iron columns in this case.

Mr. Whited. Iron columns were often used in the Western States, as the author of a recent paper had said, the principal reason being that where the load was not heavy, as in short railway and highway spans, they were much cheaper than masonry. Besides, the difficulty of laying ashlar masonry in a situation like this was very great. It was the common practice when putting in iron columns, to fill them solid with concrete, of a kind that would resist the strain and stand the weather and any other destructive agency that might be presented, so that when the iron work (which it was impossible to paint) rusted away there would remain a solid column of concrete. Referring to the beams resting on the top of these columns, they would find from the drawing that the bearing of the beams on the steel columns themselves was very slight, indeed wholly inadequate. It was evident then that they were intended to rest on the concrete and not on the steel. The beams extended only an inch or two over the side of the columns, whereas, if intended to rest on the steel, they should be over at least 6 inches. The specifications provided for iron only, with a minimum ultimate strength of 50,000 lbs., and elastic limit of 26,000 lbs. per square inch.

In large sections it was very difficult to get good iron with as high an ultimate strength as 50,000 lbs. A great many engineers were not aware of the fact, that some very poor iron was a good deal higher in ultimate strength than the very best iron. He had tested iron that went as high as 53,000 and 54,000 lbs., but which would not be used in any kind of structure, and was literally worthless. Allowance should be made, in specifying the strength of iron, for smaller stresses in large sections. He would not favor specifying anything like 50,000 lbs. ultimate strength, because the only practical way to get it was to use some cold short iron that should not be put into any structure. The elastic limit would probably be high enough, though he had tested some very poor specimens of iron with an elastic limit as high as 35,000 lbs. In framing specifications for iron, it would be advisable to provide a maximum as well as a minimum test for strength, although the elongation provided for that. The real fact of the matter was, that if a bridge of this kind were built mostly of steel, it was much better in many respects than if made of iron. In the use of iron and steel for bridges it was well known that, where angle bars and channel bars were used, there was always more or less danger of imperfect longitudinal welding, or of bending at centre of channel. In the experience of the Dominion Bridge Co., this difficulty was overcome by using steel.

The reliability of steel was at least as great as that of iron, that is to say, there were as few flaws in steel in every shape as in iron. In fact they generally looked more for flaws in iron than in steel. Iron developed weaknesses and bad defects, while on the other hand steel was improving. By specifying a mild quality of steel not over 65,000 lbs. ultimate strength, a steel that was tough and reliable would be obtained. Of course by paying a high price and procuring Lowmoor, Bowling or Swedish iron, it could be obtained as reliable as steel, but the latter was stronger and as reliable as any grade of iron one could afford to buy. In rolling complicated shapes like channel bars and I beams, it seemed practically impossible in the rolling mill to work in as good a grade of iron as could be got in square rods. If a good grade of iron was used it was liable to longitudinal flaws, not always apparent, but at least incipient in a good many cases. In designing engineering structures, the engineer sometimes lost sight of the *cost* of his structure. At the present time an excellent grade of steel could be obtained for about the same price as a good grade of iron.

Mr. Uniacke. In reply to the remarks of Mr. M. J. Butler, the iron bridges in this

Province, built under the Nova Scotia Bridge Act, have as a rule been proportioned for a rolling load of 80 lbs. per square foot, or 1200 lbs. per lineal foot for those of 15 feet roadway, which was the usual width. The Avon Bridge was proportioned for a rolling load of 1350 lbs. per lineal foot for an 18 foot roadway, and the greater length of span would be in favor of reducing the rolling load. A road roller, such as Mr. Butler describes, would be very little in excess of our calculated load at one panel point, and a procession of such rollers would not strain the iron beyond from 10,000 to 12,000 lbs. per square inch, even taking them at points 16 feet apart. The floor beams and beam hangers were specified for an increased strain of 50 per cent., the working strain was also reduced on counters, center ties and center posts. To calculate for 100 lbs. per square foot would increase the strains and sections by about 30 per cent. An increase of cost of 10 per cent., as Mr. Butler puts it, would be a very low estimate for such an increase of section.

The stones themselves remained intact, but were forced outward by the freezing of water absorbed into the piers at high water. The stone used was freestone and granite, and shewed no signs of decomposition, disintegration or fracture. The flow of ice in this river is in irregular shaped masses, from 3 to 6 feet in thickness, carried back and forth by the return and flow of the tide, discolored by sediment, and from stranding on mud flats, friable, and flowing from five to six miles an hour.

Stone piers have failed more particularly in this instance, from the fact that the tides rising and falling 30 feet leave them alternately wet and dry. The water will in time find its way under pressure into the masonry, and it is the constant immersion and freezing which is so destructive. Ice flows did not destroy the piers. Hemlock and spruce timber was used without any creosoting or other preservative.

Mr. Blackwell is right in his surmises. The cribwork had been carried up higher than shewn in the drawing, and the columns are now only directly exposed to the action of salt water during the period of high tide.

Mr. Irwin thinks there is a large amount of cross bracing, etc. This is true, but as the extraneous forces acting on the piers are uncertain and fitful, extra bracing was put in to withstand them, and, taken together with the additional cribwork and sheathing, the two columns are practically one up to high water mark.

At low water, the flow of the river is fresh water; at high tide the water is salt, but mixed with a large quantity of fresh water. The

water is not clear, but carries a large amount of sediment at all stages of tide. No scour appears around these piers.

There is no teredo in this locality. The *limnoria lignorum* is very active in the *clear* waters of the Bay of Fundy, but does not live here, owing to the large amount of silt carried in deposit and to the quantity of fresh water discharged.

Mr. Blackwell thinks that $\frac{3}{8}$ steel will not stand the chemical action of salt water. This is an important statement, and is a question which received careful attention before the work was designed. As already explained, the columns are only directly exposed to the action of salt water during high water. Again, all exposed parts are accessible to the paint brush, but the most convincing fact is, that bolts and plates used in the construction of the old bridge 50 years ago, and exposed to salt water at different stages of the tide, shewed not the slightest corrosion, and the surfaces were *bright*. This may be explained by the friction of the grit and sediment carried in the water acting on the surfaces.

Mr. Whited's remarks require some attention, and the writer regrets that enough information was not given to enable him to fully discuss the question. The specifications with regard to the quality of iron were as rigid as those generally adopted, and were very full and explicit. It was hardly necessary to burden the Society's Transactions with a verbatim copy of bridge specifications, somewhat lengthy, but possessing nothing new or of interest beyond the special requirements of the case. All the iron work directly exposed to the action of the water is, as already explained, easily accessible to the paint brush. The top beams supporting the weight of trusses are supported by both the concrete and the shell; it will be seen from the plan that the entire top is covered by a plate with voids which were left, so that, in the event of any settlement of concrete, cement may be introduced to bring a bearing on the concrete. Mr. Whited's remarks in this instance are inapplicable.

It was considered preferable to have the compression members built of iron with a lower working strain, and consequently a larger section, than to substitute a smaller section of steel, proportioned to a much higher working strain.

Londonderry iron was specified, and it has always been found reliable. The writer does not consider that Mr. Whited has shewn that there is a weak or objectionable point in the structure.

Thursday, 31st October.

P. A. PETERSON, Vice-President, in the Chair.

Student's Paper No. 3.

WOOD FIBRE FOR PAPER-MAKING.

By F. A. BOWMAN, M.A., B.E., Stud. Can. Soc. C.E.

After a brief sketch of the origin of paper, and of the various raw materials which have, at times, been employed in its manufacture, the author proceeds as follows:—

The ordinary merchantable varieties of wood-fibre are divided into Mechanical or Ground Wood Pulp, Soda or Chemical Wood Fibre, and Sulphate or Acid Wood Fibre. This is the order in which they have come into the market, and technically they should be arranged as follows: mechanical wood pulp, being wood ground to a pulp on a grindstone, with the fibres only partially separated, and all the incrustating materials still in it; sulphite fibre, being wood partially boiled in an acid solution until the fibres are completely separated, but some little silica still remains; soda fibre or wood, completely boiled in an alkaline solution, until it is a pure vegetable fibre or cellulose.

Mechanical or ground wood pulp cannot be called a fibre at all, as the wood is merely separated into particles, regardless of the natural fibre, and containing all the resins and silicious matters.

In discussing wood pulp and fibre, the question has often been put to the writer: "Cannot sawdust be used to make pulp?" It cannot be used successfully, as the saw has cut the fibres too short. Many experiments have been tried, and a kind of pulp produced from it, but it is useless for any purpose, except perhaps as a filling material to other fibres, or, in other words, as an adulterant.

The process of manufacture of ground wood pulp is simple, and consists in rasping off the particles parallel to the fibres by forcing the wood against a grindstone. The Voelter process is the best known and most used on this side of the Atlantic.

The wood is completely barked, cut into one-foot lengths, and the knots bored out; if large, the stick is split. The principal part of the apparatus is the grindstone, which is about 4 feet diameter, and 15 inches face. Its axis is set horizontally, and it makes 150 revolutions per

minute. The wood is pressed against the stone by shoes at the end of screwed rods, which slowly advance as the wood is ground off. A stream of water plays continually on the stone, and washes off the pulp. The pulp, much diluted with water, passes over a series of revolving drums, covered with wire cloth increasing in fineness. The drums have hollow trunnions, and the pulp which passes through the wire runs out through the trunnions to the next finer drum. The product is 50 per cent. of the rough wood employed. A Voelter machine uses 50 horse-power (French), and produces 500 kilos. of saleable pulp a day.

In the Grellinger process the wood is held against the side of the grindstone instead of the edge, and the patentees claim that the pulp produced is longer and better than that from the Voelter machine. The principal advantage is that the pulp is never reground, while on the Voelter machine part of the wood ground on the top of the stone runs down and gets reground at the lower shoes. In the Grellinger process, centrifugal sorters are used instead of the drums of Voelter.

The woods principally used in making both ground pulp and true fibre are spruce, poplar, and a little hemlock. The dense hardwoods are practically useless as fibre producers, either when ground or boiled. The fibres are too small and weak to be of any use.

Vegetable fibre, or cellulose, forms the principal part of every vegetable. The chemical formula for it is $C_6 H_{10} O_5$, and its composition varies very slightly, as is shewn by the following table from Wagner's Chemical Technology:

Material of Cells.	Wood.	Cotton.	Flax.	Paper.
Carbon	43.87	43.30	43.63	43.87
Hydrogen	6.23	6.40	6.21	6.12
Oxygen	49.90	50.30	50.16	50.01
	100.00	100.00	100.00	100.00

The properties which make a vegetable fibre suitable or otherwise for paper-making are entirely physical. All fibres adapted to spinning into textile fabrics are well suited to the manufacture of paper, and some that are too short for the former purpose are still very suitable for the latter. In this latter class are found all kinds of wood fibres. Cotton fibres have the peculiarity that when dried they twist spirally like a corkscrew, which, of course, much increases their felting power.

Flax fibres have sharp points arranged along them, which serve the same purpose. Wood fibres, when freed from the incrustating materials, are in the form of a flattened ribbon with thickened edges, and composed of thin transparent membranes. Mr. Aimé Girard has made a careful microscopical examination of the various fibres used in paper-making, and in a paper read before the French Academy, gives the following as the result of his investigations: The fibres after pulping, that is, when ready for the paper machine, are one-sixteenth inch long, and in very fine pulps one-fiftieth or less. He finds that fineness is essential, and considers that the fibre should have a diameter of one-fiftieth of its length, and that strength is of not so much consequence as, when paper is torn, the fibres are not broken but merely slit apart. The fibres should be elastic. He divides them into five classes: 1st. Round fibres freely flexible and elastic, as flax and hemp. 2nd. Similar fibres of a smoother and less vigorous kind, as jute, esparto, hop, dwarf palm, sugar cane, etc. 3rd. Fibre cellular matter, derived from straw, and containing both fibres and cellular matter. 4th. Flat fibres, such as cotton, and the wood fibres produced by chemical processes. 5th. Imperfect material, such as ground wood; this is not flexible enough.

The method known as the soda or alkali process, by which chemical or soda fibre is produced, was invented about 1870. The first works erected were at Manayunk, Pennsylvania. In England and other countries, where wood is scarce and high priced, few manufactories have been started, but there are a large number in the United States and on the continent of Europe. The wood employed is generally pine or spruce, sometimes aspen or poplar. It is cleaned of bark and knots, and cut into chips of a uniform size and thickness, by a machine with revolving knives. These chips are packed into a boiler about 40 feet long and 4 feet diameter, and a strong solution of caustic soda is pumped in. The boilers are heated by steam, and the wood cooked under a pressure of about 150 lbs. to the square inch for from 5 to 6 hours. The boiling and washing processes are similar to those employed for rags, esparto, etc., except that the solution is stronger. When the wood comes out of the boiler, it is still in the form of chips, but if rubbed between the finger and thumb, it separates into fibres, and is now ready to be treated by washing, bleaching, beating, etc., like any other paper-making material. The pulp is of a dark brown colour, and always requires bleaching, except for the common brown papers. The process of regaining the soda from the "black liquor" of the boiler, essential in boiling rags, etc., on account of the saving of expense and the prevention of the pollution of rivers, becomes absolutely necessary in boiling wood, on account of the much larger quantity of soda used.

The regaining is accomplished in the following manner: The spent liquor from the boiler is evaporated to dryness in pans, and the residue burnt, the result being the removal of all organic matter and the production of soda ash; the latter is causticized by dissolving it in water and agitating it in a tank with lime. The soda ash is crude carbonate of soda, and the agitating of the solution with lime produces carbonate of lime and a solution of caustic soda. For every ton of soda ash causticized, 9 to 15 cwt. of lime are required. In the best plants, 75 to 80 per cent. of the original charge of soda in the boiler is regained. The necessity for this regaining plant severely handicaps this process.

The next process to be considered is the sulphite wood fibre or acid process. This is the last to be developed, although prior in invention to the soda process. Benjamin C. Tilghmann, the inventor of the sand blast, and a resident of Philadelphia, took out a patent in 1867, for the treatment of wood with bisulphite of lime, in order to remove the incrustating materials. He never developed the process, and consequently the patent lapsed and became public property.

Dr. Mitzcherlich, the celebrated German chemist, was, at the time of his death, carrying on a series of experiments with bisulphite of lime as a boiling solution for wood pulp. His nephew, a paper-maker, and present owner of the Mitzcherlich patents, appropriated the results of these experiments, and took out a set of patents on the process and on the machines and boilers connected with it. His patent on the process was cancelled some years later, as it was identical with Tilghmann's. He cuts his wood into discs and prepares his solution in towers, but comparatively little is known of the process, as all employees and licensees are under oaths of secrecy. The other patent sulphite processes are the Francke, the Ekman, the Graham, the Olive and Partington, the Flodquist, and the Ritter-Kellner. In all these, except the Ekman, the chemical employed is bisulphite of lime, and the patents are on the boilers, the wood-preparing machinery and the method of preparing the solution. Mr. Ekman employs bisulphite of magnesia. Of these processes the Francke and the Ritter-Kellner are the most important and practical; the Ekman, the Graham, and the Olive and Partington are employed in a few mills.

The following descriptions of the sulphite process and the figures of cost refer to the Francke system, but are generally applicable to the other practical methods. The wood comes to the mill in six-foot lengths with six strips of bark peeled off to facilitate the complete barking. These sticks are cut by a circular saw into two-foot lengths, which are passed to the borers, who bore out all knots with machine augurs. They are then barked by a machine which is really a revolving plane. It is an abso-

lute necessity to have all bark removed, as nothing in the process touches it; it comes out from boiling and bleaching unscathed, and appears as a brown speck in the paper. The clean wood is fed into a simple vertical barking plane that cuts it into small chips, which pass slowly down an inclined shoot, along each side of which women are stationed to pick out knots that may have escaped the borers. It is now ready for the boiler.

The solution employed to boil the wood in is bisulphite of lime, this is a combination of 2 parts of sulphurous acid with 1 part of lime. It is a colourless pungent liquid, which emits sulphurous acid gas, and in time by exposure to the air becomes oxidized into sulphate of lime, the sulphurous acid also forming sulphuric acid. When boiled with wood at a pressure of 60 to 65 lbs. to the square inch, the solution is forced into the pores. The sulphurous acid is set free, and the lime combines with the resin of the wood to form a soluble resinate. Small quantities of sulphate of lime are produced during the boiling, and care has to be exercised to prevent its being mixed with the fibre. One style of boiler is especially designed to this end.

The preparation of the solution is simple. Sulphurous acid is generated from pyrites in ovens similar to those used in the manufacture of sulphuric acid. The fumes of acid are led to the bottom of a tower 40 to 90 feet high. This tower is divided into several shafts by solid partitions, and each shaft is provided with gratings at certain points. On these gratings are piled blocks of limestone. A large tank at the top of the tower supplies a steady rain of water that trickles down over the limestone. The fumes of sulphurous acid rise through the shafts and combine with the limestone to form bisulphate of lime, which is absorbed in the water, and runs into tanks at the bottom of the tower, whence it is conveyed to the boilers.

The boilers used by Mr. Francke are 40 ft. long and 7 ft. diameter, of steel, lined with $\frac{1}{4}$ inch of lead. They are set horizontally on friction rollers, and revolved by spur gear. Steam is admitted by a pipe with a trunnion joint situated in the axis of the boiler. The lead lining in these boilers is the greatest source of trouble connected with their management. Everything that the solution comes in contact with must be protected with lead. The coefficient of expansion of lead is more than twice that of iron, and in addition, lead is so inelastic that on cooling it does not return to its original size. When expanded by the heat of the steam, the lead plates confined by the iron shell must buckle. This repeated buckling and straining of the plates rapidly crystallizes them, and then they crack, letting the solution through to the iron.

Many patents have been taken out to counteract this defect, the principle involved in most of them, is the dividing up of the lead into small areas, by fastenings placed close together, so that the buckling action is almost nil. Mr. Francke fastens his lead lining in by iron rings sprung out against it, these, of course, being lead-covered.

Steam at 65 lbs. pressure is employed for the boiling, and is injected directly into the boiler. The boiling lasts from 12 to 16 hours, according to whether the charge is to be subsequently bleached or not, that to be bleached being boiled the longest.

When the boil is finished, the steam and sulphurous acid are blown off into a solution tower, and regained immediately as bisulphite of lime. The charge in the boiler is washed with three washings of cold water, which clean the pulp and cool the boiler, which is then revolved until the charging hole is down and the contents are emptied into draining vats. A man enters the boiler and inspects the lining before the next charge is put in. On coming from the boiler, the pulp is in fragments, representing the original chips; but if rubbed, these break up into fibres; the stuff is put into a beating engine, and a very little beating reduces it to a perfect pulp. The unbleached Francke pulp, as it comes from the boiler, is white enough for many common printing papers. When the bleaching liquor is added to the pulp, a curious action takes place. The pulp immediately turns a distinct red colour; this gradually fades to a dull yellow, and finally disappears as the bleaching action continues. The bleached pulp is snow white.

The following figures of cost of production were calculated for England, by Mr. W. F. Catchside, and are very easily adapted to any particular locality, the sterling amounts have been converted into Canadian currency.

Building for whole of wood machinery, boilers, etc. (brick)..	$7500 00
Tower containing 4 shafts (brick).....	5000 00
Pyrites furnaces and flues (2).....	1500 00
Steam boiler (1).....	3000 00
Cisterns (lead lined), $\frac{1}{8}$ inch (3).....	2500 00
Fibre boilers, steel and lead lined, fitted complete (2).....	12000 00
Circular saws, wood machinery fittings, etc.....	5000 00
Engine 40 H. P. (nominal?) to work hoists to tower, for wood, boiler and pumps.....	2500 00
Total cost.....	$39000 00

say $40,000.

The cost of producing 30 tons a week, for which the above plant is suitable, is as follows:—

36 cubic fathoms of white pine wood (216 cubic feet) delivered at British port, at $14.61 per fathom	$525 96
Labour (weekly)	182 01
Coals (60 tons at $1.94)	116 88
Gas (for lighting)	9 74
Pyrites (20 tons at $4.87)	97 40
Limestone (2 tons, at $2.44)	4 87
	$936 86
5 p.c. interest on $40,000, cost of plant	40 00
10 p.c. " " " wear and tear	80 00
2½ p.c. " " " rates, etc.	20 00
	$1076 86

Cost per ton, $35.89.

The labour employed by Mr. Francke's mill is as follows:

Sawing, 2 men at steam saw, each 6 hours	12 hours.
Boring, 1 man at machine	9 "
2 boys helping, each 9 hours	18 "
Cutting, 1 man at machine	9 "
1 boy helping	9 "
Sorting, 12 women, each 12 hours	144 "
Boiler gang filling boilers, emptying drainers, etc., 5 men, each 12 hours	60 "

In preparing the wood for one day's work, of 5 tons, there is required in labour:

Men	90 hours.
Boys	75 "
Women	144 "

The men's wages are taken at 85 cents a day, and the women and boys at 48 cents. Adding 2 more boys, who will be useful, the cost of labour per day of 12 hours will be

7½ men, at 85 cents a day	$ 6 38
20 women and boys, at 48 cents	9 60
	$15 98
Labour on wood cleaning, etc., per week	$101 88

Other labour is as follows:—

2 men at fibre boilers, at $6 a week	$12 00
2 " stoking at steam boilers, same wages	12 00
4 " pyrites ovens, at same rate	24 00
2 foremen, at $9.50	19 00
1 plumber, at $8.50	8 50
Extra labour on tower occasional	5 00
	$84 15
Wages for wood, etc., as above	101 88
	$186 03

One ton of pyrites composed of one-third, containing 40 per cent. sulphur and the rest 36 per cent. sulphur, will furnish in Francke's towers 750 to 1200 cubic feet of solution, according to the weather, at 4° to 4½° Beaumé. Each boiler requires 725 cubic feet at 4° Beaumé.

Mr. Ekman was manager for Mr. Francke for some years, and on leaving him took out a set of patents of his own, and erected a mill at Söderham, on the Baltic. This is one of the large lumbering ports of Sweden, and he employs the slabs and deal ends from the saw mills as raw material. The principal difference between his process and the Francke is that he employs bisulphate of magnesia instead of lime. The raw materials for his solution are magnesite, which he imports from Greece, and sulphur from Sicily. He uses fixed vertical boilers of a smaller size than Mr. Francke's.

The most important part of the Graham process is the lead lining, which is attached to the iron shell by bolts placed short distances apart, the heads being covered with lead.

Messrs. Olive and Partington, of Lancashire, England, have patented a solution apparatus and a lead lining of their own. They employ spherical rotary boilers with an inner shell of thin iron coated on both sides with lead sheets, and the three plates are rivetted together at short intervals, with lead rivets. Their solution apparatus consists of a series of tubs. There is a mill at Sheet Harbor, Halifax Co., N.S., working on their system.

Mr. Flodquist, of Göthenburg, Sweden, combines the manufacture of glue with that of his solution.

The Ritter-Kellner process, of which Eugen, Baron von Ritter and

Mr. Charles Kellner are the inventors and proprietors, is the latest and one of the most important. Baron von Ritter is an experienced practical paper-maker of Gortz, Austria, and Mr. Charles Kellner, manager of his cellulose works, a professional chemist and engineer, so the probabilities are in favour of their process being the most practical and scientific. Mr. Kellner claims that he discovered the suitability of bisulphite of lime as a boiling solution for wood fibre independently, without any knowledge of Tilghmann's patent, in 1871, while experimenting to find a wet method of regaining the soda from the spent liquor of the alkali process. The Ritter-Kellner wood-cleaning apparatus is admirably adapted to its work. The wood is cut into lengths, barked, the knots bored out, then split in a special machine, and cut into chips, which are put through a sort of bark mill which reduces them to a uniform size.

The solution is prepared in a series of tubs filled with dolomite, the water and the sulphurous acid fumes being forced through in opposite directions by pumps. The amount of solution produced is thus independent of the weather.

Thursday, 14th November.

P. A. PATERSON, Vice-President, in the chair.

The following Candidates having been balloted for were declared duly elected as

HONORARY MEMBERS.

SIR JOHN FOWLER, K.C.M.G.
SIR JOHN HAWKSHAW, F.R.SS.L. and E.

MEMBERS.

WILLIAM DUNCAN BARCLAY, HORATIO FREDERICK FORREST,
ALEXANDER STEWART.

ASSOCIATE MEMBERS.

WALTER PECK CHAPMAN, LEWIS W. TOMS.

ASSOCIATES.

THOMAS C. BRAINERD, M.D., SIR GEORGE STEPHEN, *Bart.*

STUDENT.

ALEXANDER SCOTT DAWSON.

The following has been transferred from the class of Associate Members to that of Members:

ELZÉAR LANTIER.

THE CORNWALL CANAL.

By S. Keefer, M.Can.Soc.C.E.

Paper No. 34.

Of the first construction of the Cornwall Canal, during the years 1834 to 1839, it is proposed in this paper to present to the Society such an account, from personal knowledge, as an assistant engineer, resident on the works during those years, is qualified to give. Reference to the enlargement thereof, now in progress, will also be made as an engineering question.

The Cornwall Canal was the first of the series of canals on the St. Lawrence, constructed for the larger scale of steamboat navigation. In 1832 the Legislature of Upper Canada appropriated the sum of $280,000 for the improvement of the navigation of the St. Lawrence, to admit the passage of vessels drawing *nine* feet of water, and recommending the immediate commencement of the improvement between Cornwall and the Long Sault Rapids, stipulating for the completion of the Cornwall Canal before any other works leading to Lake Ontario should be undertaken. A commission was appointed in 1833 to carry out the provisions of the act, and by them the surveys and plans for the works were entrusted to experienced engineers from the United States.

The preliminary survey was conducted by Mr. John B. Mills as chief engineer, with Mr. Benjamin Wright, or Judge Wright, chief engineer of the Erie Canal, as consulting engineer. Mr. Mills brought with him three assistants, and the writer made the fourth. Mr. William J. McAlpine took the levels. The writer made the survey, and Mr. James Worrall and Mr. Charles Mills were the draughtsmen. The field work was soon accomplished. It was begun the 13th May, 1833, and completed 2nd July of the same year. The engineers then proceeded, under the same authority, with the survey of the St. Lawrence thence to Lake Ontario, and submitted plans and estimates for the canals proposed to be constructed at the Long Sault, Farran's Point, Rapid Plat, Point Cardinal, and the Galops, amounting in all to $1,294,464. In September and October of the same year, the writer assisted Mr. Mills in the survey for a canal in continuation of the Cornwall Canal, and of the same dimensions, in Lower Canada to

connect Lake St. Francis with Lake St. Louis, and to overcome the rapids at Coteau, Cedars and Cascades. This survey was confined to the North Shore, and referred to two routes, one along the river bank at these rapids and the other inland.

The following year, 1834, the final location of the canal was begun at Dickinson's Landing, at the head of the Long Sault Rapids, on the 20th May. On the 30th of the same month the Canal Commissioners, of whom Mr. Jonas Jones of Brockville was president, came down to examine the plans and proposed line of canal. They were accompanied by Captain Cole of the Royal Engineers, by their chief engineer, Mr. J. B. Mills, by Judge Wright, the consulting engineer, and by Judge Geddes, another engineer from the Erie and Champlain Canals. As the two American engineers, Judge Wright and Judge Geddes, had borne conspicuous and responsible parts in the construction of the Erie Canal, it was considered that their knowledge of canal works would be valuable to the Commissioners. Captain Cole and Judge Geddes had been specially retained to advise the Board in reference to the selection of the best line for the canal. Mr. Mills had served under Mr. Moncure Robinson, an accomplished and distinguished engineer of Virginia, and came to his work in Canada well informed, and with perfect confidence in his own ability. He was a man of great determination, and having once made up his mind as to his plans, and the course he intended to pursue, he was immovable.

As the result of this examination by the Commissioners, and the engineers both civil and military who attended them, the chief engineer's plan was approved, and the works were placed under contract the same year. It may here be stated that with the exception of a few changes of the centre line at the Long Sault, to throw the canal more inland, the location of the canal as now constructed is the same as that originally projected by Mr. Mills, and adopted by the Commissioners.

The engineers determined on locks 55 feet wide 200 feet long between the gates, and with nine feet of water on the sills. These dimensions would allow the passage of vessels 175 to 185 feet long, according to their build. The canal was to be 100 feet wide at bottom and 150 feet at surface to admit of the side paddle steamboats then in use passing each other in any part of the canal. The great capabilities of the screw as a means of propelling vessels had not at that time been developed, and propellers were not then employed in our inland navigation. This accounts for the very generous width given to the canal.

The length of the canal is 11½ miles. There is one guard lock at the head, and there are six lift locks of 8 feet lift each, to overcome the

whole fall in the river of 48 feet, from the head of the Long Sault to Cornwall bay at the head of Lake St. Francis. This scale for the navigation of the St. Lawrence was approved by the Commissioners and adopted by the Government, and became the standard for the other short canals above Cornwall, except that as vessels could there descend the rapids outside these canals with safety, the bottom width was reduced to 50 feet. The width of the locks on the Cornwall Canal 55 feet, as fixed by the American engineers, was not in reality available for vessels of that width, owing to the peculiar form of the lockwalls, and therefore, when the Williamsburgh canals (the name given to the short canals at Farran's Point, Rapid Plat, and the Galops) were afterwards constructed, as well as Beauharnois and Lachine canals, the width was reduced to 45 feet, which was considered in better proportion to the length and draught.

An account of these locks as built, with plans of locks, lock gates and the machinery for operating them, was published with the report of Colonel Philpotts, R. E., on the proposed enlargement on the Welland Canal in 1840, and need not be repeated here. This report was made under instructions from the Earl of Durham, and was addressed to the Right Honorable Sir Charles Poulett Thompson, Governor General, and published in the "*Professional Papers of the Royal Engineers*," Vol. V, pp. 140 to 193.

THE LOCATION.

In taking his departure from the navigable waters of the St. Lawrence above the Long Sault, the choice of two lines was presented to the engineer. One was to follow along the river bank down to the channel dividing Sheek's Island from the main shore, and the other an inland route up Hoople's Creek, and by a depression half a mile back of the river to meet the same channel at Sand Bridge on Brownell's Bay. The first was along a high bluff bank rising 30 to 50 feet above the river, all side cutting, and the other a through cut.

The engineer having instituted a comparison between these two lines decided in favour of the one by the river, as being a mile and a quarter shorter, and saving $120,000 in cost. An engineer's assistant may not question the superior judgment of his chief, but loyally accept his decision, seeing he is in no way responsible.

The correctness of this estimate has recently been called in question, but whether right or wrong, no good end can be served by the discussion of it now, for the very good reason that the officially adopted line

has been constructed, and in use for half a century without accident or failure of any kind. The subject is now a dead issue.

It may be observed, however, that the front or river line being all in side-cutting with short delivery into the river, a cubic yard of material could be moved at less cost than in a through cut inland, where it has first to be elevated, and then carried some distance into spoil bank. Probably two yards could be moved on the front line at the same cost as one yard on the inland route, or double the quantity for the same cost.

THE SUMMIT LEVEL.

There can be no doubt that the engineer was perfectly right in maintaining his summit level, and carrying it on as far as he could, so as to command the table-land eastward of Milleroches, to his first lift lock, but his location of the canal along the three miles of circuitous side cutting, from the Long Sault to Milleroches, cannot be approved, when there was, as will appear from what follows, no necessity for resorting to such a hazardous location, but in view thereof, a safe and less costly means of keeping up the summit level. The maintenance of the summit level was correct in principle, because when the line had reached Milleroches, the engineer was independent of the river, and thence to Cornwall could locate his locks to the best advantage. On the other hand, many of the contemporary engineers, both civil and military, who had other plans to suggest seemed to have lost sight of this essential principle. They proposed to lock down into the Sheek's Island channel, and to render it navigable by dams at Moulinette and Milleroches, or simply by one dam at the latter place made high enough to drown out the rapids at the former. It appears this was suggested in order to avoid the great cost and risk of hanging up the canal in side cutting on the north shore; but by this proposed drop to a lower level they had to encounter a deeper cutting of some seventeen feet or more eastward of Milleroches till the first lift lock was reached. They all suggested that a low dam, to serve merely as a coffer-dam, should be thrown across the shallow channel, called the "*Snye*" at the head of Sheek's Island, to shut off the water coming down that channel during the construction of the proposed works at Moulinette and Milleroches, or possibly to serve, if maintained, as a regulating bulk head for the supply of the canal after it had been built. Mr. Peter Fleming, Mr. Samuel Clowes, Judge Geddes and Captain Cole, R. E., favoured plans of this sort; but Mr. Clowes went beyond the other engineers, and suggested a lock in the dam at Milleroches, and continuing the canal

along the margin of the open St. Lawrence to the head of the Cornwall Rapids, and thence along in front of the town to the bay below Cornwall.

Of all these rival schemes the assistant engineer was at the time entirely ignorant, and in no way concerned with them, being then actively employed in the location survey of the chief engineer's adopted line. But while so engaged, he had naturally become familiar with the physical features and capabilities of the country for canalization, and began to form opinions of his own on the subject. To him it appeared a surprising circumstance, that after all the array of professional skill that had been convened to assist the Commissioners in the selection of the most feasible plan, they should all have overlooked one simple and obvious idea that would have given a satisfactory solution of the main difficulty with which they were all contending—namely, the cost and hazard of carrying the summit level of the canal along the left bank of the river, where the surface of the canal would be from 16 to 24 feet above the surface of the river, and where the suitableness or otherwise of the material for making sound banks was as yet unknown.

The idea that presented itself to the mind of the writer was to have no canal at all on the north bank, but in lieu thereof, to raise the dams at the head and foot of Sheek's Island, high enough to retain the summit level of the canal, and transform the river valley into a fine broad basin, making that the canal. If both dams were raised to the same level, they would obviate the necessity of constructing three miles of canal along the north shore. The foundations for these dams would be secure, for they would be on hard, gravelly earth or solid rock. The width of the channel at the head of the Island is 230 feet, according to the survey presently to be referred to, and at the foot of the Island 330 feet. In both cases the water is quite shallow—the same quantity passing at both places, and the banks are high. Sheek's Island would form the south, and the main land the north bank of the canal, or basin, created by the two dams. The upper dam, if raised five feet above canal surface, would stand 26 feet high in the middle, and the lower dam 40 feet high, allowing in both cases for four feet of water in the rapids, which is believed to be in excess of the actual depth.

The idea of two dams *of the same height*, both raised to summit level, does not appear to have been grasped by any of the engineers before mentioned, and when the assistant engineer ventured to suggest it to his chief, it was treated with scant courtesy, and at once dismissed, and was never again referred to. Could it be that the chief did not understand what his assistant proposed? It is believed that a survey and

comparative estimate, if made at that time, would certainly have settled the question in favour of his plan.

THE CONSTRUCTION.

Mr. Mills remained in charge of the works as chief engineer, until 1st June, 1836; when, owing to a difference that arose between him and the Commissioners, he gave in his resignation, and was succeeded by Colonel Phillpotts, of the Royal Engineers. In the two years of his official connection with the canal, he had, with the approval of Mr. Benjamin Wright, settled all the plans for the mechanical structures and earth works, and considerable progress had been made in their construction before Colonel Phillpotts assumed command. The writer had been placed in charge of the works on the upper division, a little over seven miles in length, including the guard lock and the first lift lock, and continued in charge of the same under Colonel Phillpotts until the work was suspended.

A map of the River St. Lawrence, immediately south of the canal, has been prepared (Plate XIII), shewing the several islands and channels between them, through which the main navigable channel downwards, pursues its tortuous course, and also the boundary line between Canada and the United States. This map has been copied from the very careful hydrographic survey of the U. S. Corps of Engineers, made in the years 1871, 1872 and 1873, and is the most recent, as well as the most correct, chart extant. From this, it will be seen that Sheek's Island is Canadian, while Barnhart's Island is American, and that the channel dividing them, through which the boundary line is drawn, is not navigable, nor is the small channel between Sheek's Island and the Canadian shore fit for navigation. Therefore, there can be no reason why Sheek's Island should not be utilized for canal purposes, seeing it is only intended to rest the ends of the two dams upon it, and to flood a few acres of the low land fringing its northern border.

THE EARTH WORKS.

In order to represent more clearly the peculiar character of earth works on the first reach, four cross-sections have been plotted from the original field notes and records, and numbered 1, 2, 3 and 4. (Plate XIV.) A hand sketch marked (A) is also given on the face of the map in further explanation.

Cross-section No. 1 is given to shew the deepest cutting on Section No. 1; the Long Sault section, which is 9294 feet in length, and the enormous amount of material that was wasted in these rapids—all

carried away by the current to the lower parts of the river, in order that the prism of the canal might be cut out of the solid ground without encroaching on the bed of the river.

The material through which the canal was made along the rapids is characterized by Sir William Logan, as "*Glacial drift with boulders.*" The upper part of this section, for nearly a mile, is covered with a stiff brown clay, which was soon dissolved and carried off when thrown into the deep swift current, which at this place runs smoothly at the rate of ten miles an hour. No attempt was made to save it by crib-work or otherwise. The gravelly earth underlying this brown clay becomes gradually harder and deeper as the lower end of the section is approached, until it is developed into hard pan, and beyond the limit of the section, into indurated or cemented gravel, that required to be blasted before it could be removed. There was no more clay at the lower end of the section, and the boulders amounted to one-sixth of the entire mass. The mixture of gravelly earth and hardpan, was the very best material for making a solid water-tight bank, and it might have been economized much more than it was for that purpose. The military engineers, who occasionally visited the works during their progress, entertained the opinion that it was impossible to encroach upon the bed of the river, that the current would have its own way, that the artificial works put in it would not stand, and that the river would ultimately return to its original bed! It is very possible these opinions might have influenced the management, for the centre line was moved at the upper end from 30 to 70 feet, and then back to zero again, by gentle curves over 4,200 feet; and at the lower end from 0 to 74 feet and back again to 0, over 3,000 feet, leaving only some 2,100 feet of the original centre line unchanged.

But facts are stronger than opinions. It is a fact that the bed of the river was encroached upon along the swift broken water towards the lower end of the section, viz., on sub-sec. F. of No. 1 (Plate XIV). The hand-sketch (A) on the map (Plate XIII) explains how this was done. By taking advantage of certain salient angles or points along the rapids, a bank of earth and stones was run out to the outer slope of the canal embankment and protected by a mass of boulders. Then the boulders kept in reserve for the occasion were used to form a barrier against the river between these salient points along the outer edge of the slope, enclosing a pond of still water, which was then filled with earth to form the base or body of the embankment; the abrasion of the natural bank by the current during the ages past had favoured these operations by forming a margin of comparatively shallow water between the projecting

points, varying from 6 to 10 feet deep, whereas further out, from soundings taken in the rapids, the depth was from 20 to 30 feet. The bank built in this way has stood firm to this day, and must be considered permanent. Much more good work of this kind might have been accomplished to economize the material, had the plans been previously arranged for it.

Cross-section No. 2.—This section is taken a short distance below Moulinette, and is a fair sample of the doubtful character of the soil on which the integrity of the navigation depends. It was near this that the *first* breach occurred in December, 1843, shortly after the canal was first opened. Small streaks of sand were found in excavating the canal, which made their way in some unknown manner through the natural "*drift*" on which the embankment rests. These where discovered were cut off by a puddle trench, six to eight feet deep, and the bank and canal bottom protected by an apron of puddle three feet in thickness. The *second* breach took place on the 30th October, 1850, just above the road culvert at Moulinette, after the canal has been seven years in use. The cause of the breach in this instance was attributed to a small rivulet that crossed the canal nearly at right angles, some fifteen feet below the bottom of the canal. It was a sort of blind water-course that had not been thoroughly cleared of the sand and vegetable deposits before the bank was built across it. Through this, without any previous warning, the canal water found a passage, and in a very short time, a gap 280 feet long and 26 feet deep was made, emptying the canal, and carrying away some 1500 cubic yards of the bank. The gap took the following shape. Fig. 1.

The writer at this time was Chief Engineer of Public Works, and on him rested the duty of restoring the navigation in the shortest possible time, so that the fall fleet might be passed through before the close of navigation. He at once repaired to the spot, and with the assistance of Mr. Duncan McDonald, the local superintendent, and a strong force of men and horses working night and day, the breach was made up to full height in ten days—the water let in on the 9th day—and on the 12th of November he was able to report to the Department that the navigation was fully restored, and that all the delayed vessels had passed through.

Before the canal was filled, the writer walked down the canal bank to Milleroches to make an inspection of the empty canal. He found a eak in the bottom of the canal some distance below the *cross-section No.* 2, where the water was running out in a considerable stream into the French drain that had been put in to drain off the springs in the natural soil. This drain was five feet under canal bottom, and near the toe of the bank; see Fig. 2. Some bad material was found

in the bottom of the canal through which the water found a passage to the drain in a stream the size of one's arm, and passed under the bank to the river by the French drain here shown. If the breach had not occurred at Moulinette as it did, one would most surely have happened here. The bank had a narrow escape.

Cross-section No. 3.—This section is taken 1400 feet east of No. 2, Plate XV, near the place where the *third* breach, the most serious of all, occurred on the 11th Oct., 1888. It will be observed that there is no excavation here. The work is altogether in embankment—an embankment that rests half on the land and half in the bed of the river, which at the end of the slope is 38½ feet below the bottom of the canal. The river bank is 8 feet below canal bottom. The soil is clay, out of which arise natural springs, which during construction were led out to the river by longitudinal and transverse French drains under the seat of the embankment. This expedient was by no means effectual, for when the bank had been raised nearly to its full height, even before the water was let into the canal, the outer slope began to slide off towards the river. The springs received into the drains, rose up in the outer slope and softened the bank, and of course it must yield to the superincumbent weight of the more solid material resting against it. To remedy this evil a series of cross diagonal drains was sunk in the outer slope to carry off the leakage. A good deal of this kind of protection had to be resorted to during the progress of the work; but when all was done and the outer slope protected by rip-rap, it is evident, from the facts stated, that there could be no assurance that the bank would be permanent. A clay soil infested with natural springs, whose source is unknown, is submitted to a pressure of 22 to 24 feet head of water—the diff rence between the water in the canal and the water in the river. The quantity of water

that leaks out through the bank may be trifling at first, but the power exerted by it for mischief is not measured by the actual volume of water that leaks through (as is well understood by what is known as the "*hydrostatic paradox*"), but is in direct proportion to the sum of the vacant spaces within the bank or area on which the pressure is applied. This power, constantly acting on the clay soil forming the outer slope of the bank, first softens it, and then it gives way to the pressure from above, causing slides.

A gravelly soil on the other hand stops its own leaks. The earth and sand and gravel rush in and close them. Herein is the great difference between the banks constructed past the Long Sault where the material is gravelly earth, and sand, and stones, and the treacherous clay soil over which the canal has been formed between Moulinette and Milleroches. The former have never failed, the latter have failed three times, and many more failures have been averted by constant inspection and prompt repairs.

The breach which occurred in this vicinity in October, 1888, no doubt exemplified the hydrostatic law before referred to, for after it was nearly closed another slide took place and materially retarded its completion. This, with the almost incessant rains, delayed the navigation 32 days, and raised the cost of repairs to nearly $50,000.

It must be admitted that the foundation of the embankment here is by no means reliable, nor is it likely that it can be made so at any reasonable cost. Certainly it is not a foundation such as an engineer would select for the base of a dam, for while the bank of the canal must maintain the water in it from 16 to 24 feet above the river, it is in reality a dam in every part of it throughout its three miles of length.

Although your attention has not been particularly directed to the character of the canal, between Moulinette and the Long Sault—or rather Brownell's Bay, it must not be inferred that this part affords no cause of apprehension. So far, it is true, no breach has happened here, but it must be observed that it rests on a clay soil, covered with a deposit of sand and loam, and the water in the canal stands 16 feet above the water in the river. A great body of this sand and clay was carried from the side cutting to form the embankment in Brownell's Bay, which had many years to settle and consolidate before the sixteen feet of pressure was put upon it. At the same time the removal of so large a mass of material from the side cutting for building this bank, prepared a more secure site for the canal. Still it is a canal in side

cutting, and for that reason is less secure and more exposed to accident than a canal in a through cut.

Cross-section No. 4.—Plate XV. This section is taken about a quarter of a mile above the first lift lock, and represents the retaining wall built in the bank by Mr. Mills. Before the canal was begun, land slides were observed in the high bank along the river, which at this place is *forty* feet below the surface of the canal. They were caused by springs in the natural bank. As a matter of protection to the canal, a wall, as shown, was built for a quarter of a mile in length along the line of the outer edge of the towing path, founded on a solid timber platform, supported on piles. The wall is built of heavy ashlar masonry, laid dry, so as to allow the spring water to pass anywhere freely through it. The clay excavated from the prism of the canal was thrown in spoil bank in rear of this wall, and as the top of it was 3 feet under top bank it is now entirely covered in and hidden from view. It extends from sta. 335.50 to sta. 349.60 of the original survey, and contains 9,037 cubic yards of masonry.

In constructing the canal, sand streaks running through the clay were discovered in the bottom, by which the water found a passage to the revetment wall and through it to the spoil bank outside. In August, 1836, a slide took place here, which carried away part of the original bank within *five* feet of the foundation of the wall, and exposed 6 to 8 feet of the natural bank below it. From a note made at the time, it was thought that the part (A) sunk down to the place (B) and pushed out (C) before it—(B) and (C) having first been softened and prepared to slide by the water leaking through the wall. To stop the leaks a puddle trench 8 to 10 feet deep and 4 feet broad at bottom was placed along the foot of the slope, and joined to an apron of puddle three feet in thickness, protecting the bank to its top. This method of protection was entirely successful, and there have been no further slides, nor any failure of the wall up to this time.

The rebellion of 1837 interfered seriously with the progress of the works on this canal, and finally, with the financial embarrassments that followed, brought it to a stand. The writer left in 1839. In 1841 a "*Board of Works*" (afterwards "*the Department of Public Works*") was established for the united provinces of Upper and Lower Canada with the Hon. H. H. Killaly, C.E., as chairman, and the writer as Chief Engineer. Under that Board the canal was so far completed in 1842, that the steamboat "*Highlander*" was passed through in December of that year, but the formal opening did not take place until June, 1843. No important works in connection with this canal have since

been executed, with the exception of the construction of regulating weirs and sluices around the locks, to supply water power to the mills at Cornwall.

The total expenditure on this canal up to the date of confederation, 1st July, 1867, was $1,933,152.

THE ENLARGEMENT.

The Canal Commission of 1871 made an attempt to fix the scale of navigation for our canals, They recommended the enlargement of the Welland and St. Lawrence Canals for a draught of *twelve* feet, with locks 270′ × 45′ × 12′ in the chamber. That scale was approved and adopted by the Government; but when the enlargement was begun on the Welland, strong representations were made by the merchants of Montreal and others interested in the navigation, that the draught should be increased to *fourteen* feet, and the Welland and Lachine Canals have been finished to that depth, while the length and breadth of the locks remain the same as recommended by the Canal Commission. Skipping the Beauharnois Canal for the time, the enlargement of the Cornwall Canal was begun at each end—the middle portion was not placed under contract until near the end of last year.

Three years before this work was placed under contract, the writer ventured to lay before the Minister of Railways and Canals the facts that had come to his knowledge, in relation to the doubtful nature of the foundation on which the old canal rests. This was done by a memorandum dated 17th Feb., 1885, which has recently been printed by order of Parliament, along with the correspondence in reference to the great breach of October, 1888.

It has been stated that it would be injudicious to cut into the north side of the embankment, and that the widening must all be done on the landward side, the south bank allowed to remain undisturbed, and the slope on the canal side continued down to the new bottom line at the same angle as at present. Thus it appears that all the material dredged out is to be put on the south side of the bank.

Also that placing the dredged material on the outside is not the position where it would be most serviceable to banks of the description these are represented to be, still the material will have a sectional area, and be of a nature that when fully consolidated would *almost, if not altogether*, retain the water in the canal, were the old banks opposite the respective places removed altogether.

In order to illustrate the effect of the *modus operandi* to be pursued in the enlargement, both on the bottom and slopes of the bank, attention

s directed to the cross-sections No. 2 and No. 3 (Plates XIV and XV), on which the bottom line and slopes of the enlarged canal are drawn. In sinking the bottom 6½ feet deeper, the dredge will remove the puddle trench and puddle apron on the bottom of the old canal, and will expose the streaks of sand in the original bank of No. 2 to a severe pressure. The banks at both places, being on unsound bottom, cannot be benefited by all the spoil bank dumped on the outside of it, but on the contrary must be rendered more liable to accident than at present, by these operations.

It is perhaps necessary here to state that the *cross-section No.* 4 presents a condition of things to which no reference is made in the specification for Sec. 5, as nothing is said of the revetment wall, and the puddle trench and apron in front of it. Special means will have to be adopted in order to protect the canal from leakage along the front of this wall, and thereby prevent land slides.

THE "SNYE." *

With respect to the suggestion to convert the Sheek's Island channel, or "Snye," into slackwater navigation by means of dams at either end, it is argued: (1) That the closing of the "Snye" may produce the most serious floods, and lead to complications with a foreign country. (2) That however insignificant this small channel may be, compared with the great St. Lawrence, it runs in the same direction as this branch of the river at the head of the Beauharnois canal, the closing of which led to a vast deal of trouble and outlay for land damages. (3) That the St. Lawrence is on too grand a scale to admit of the probable result of interference with it, to be even approximated by the use of formulæ fairly applicable to ordinary streams. And finally, (4) That all dams are insecure. On the question of comparative cost, no opinion is expressed.

It is now proposed to examine these four points: (1) Any person acquainted with the locality would be surprised to learn that the closing of the "Snye" could possibly lead to complications with a foreign power! The term "Snye" is applied in this immediate neighbourhood more particularly to the small channel at the head of Sheek's Island. It starts from about the middle of the length of the Lost Channel, nearly at right angles with the same. The banks of the St. Lawrence on either side are high, and cannot possibly be affected by the closing of the "Snye." (2)

* The English equivalent, among river men, for the French original "chenail."

It is an unusual thing for the rapids of the St. Lawrence to be frozen over in winter. The ice jam that occurred at Weaver's Point, in January, 1887, was unprecedented. It may never happen again, but if it should, it can do no harm to the proposed dam at the "Snye," for it will be five feet above the flood, and will effectually protect the canal. As for the main river, the banks being high, they cannot suffer damage. They are nature's barrier against such disturbing forces. The reference to the dam at the head of the Beauharnois canal, which closed up a branch of the river, is not a parallel case, nor is there any danger in closing the "Snye," from the fact that it *runs in the same direction*! (3) The St. Lawrence is indeed a mighty river, grand and lovely. The writer, having dwelt along its borders all his lifetime, respects its magnitude, and loves its beauty and the purity of its waters. Still he considers it amenable to the laws of nature, and must not be prevented tracing out the effect of closing an unnavigable channel and turning it to the service of man. At Fort Erie, where it issues from Lake Erie, under the name of the Niagara river, its discharge, as measured by Mr. Barratt, is 24,000,000 c. feet per minute, that being the least quantity continually flowing over the Niagara Falls. At the Cascades, where it falls into Lake St. Louis, Mr. James Stewart found the discharge 27,384,640 c. feet per minute. It may therefore fairly be assumed that the volume discharged through the various channels, between the Islands at the Long Sault, is 26,500,000 c. feet per minute, and yet the St. Lawrence is not a torrential river, while from the remoteness of its sources of supply it is affected but very little by local rains or floods, and the range between high and low water is of very limited extent. It is a gently flowing stream all the way from Kingston to Montreal, except where broken by rapids. As regards the "Snye," its ordinary discharge is about 200,000 c. feet per minute. Compare this with the whole volume of the main channel, and then adopting Dr. Robertson's law, that "the squares of the discharges are as the cubes of the hydraulic mean depths," and it will be found that the only effect of closing the "Snye" will be to raise the water about *one inch* in that part of the main channel, immediately opposite Sheek's Island and Barnhart's Island, for both above and below these islands the discharge will be constant—dam or no dam. Moreover, the main channel here is divided by an imaginary boundary line between the two neighbouring countries, and the theoretical rise of one inch will not be observable south of that line, while on the American shore, the rise will be nil. Two civilized countries are not likely to quarrel over a paltry question of this kind. (4) As before stated, the foundations for the

dams, and the materials at hand for their construction, are of the best order. An engineer could desire nothing better. There is no reason, therefore, why they should not be made as permanent as the hills. If all dams are ruled out as insecure, it follows that a canal bank three miles long, every part of which is a dam, must be more liable to accident than two dams aggregating about a quarter of a mile in length, including the approaches.

Practically, the best interest of the navigation will be served by the dams, for it must be observed that they can be constructed without any interference whatever with the navigation. The old canal will not be encumbered by the dredges, and the dams could be completed in half the time required for the dredging, and at less than half the cost.

Reference has been made in the printed correspondence before mentioned, to the water power that will be created by making Sheek's Island channel a portion of the canal. Incidentally this is a great advantage; for, while navigable canals are not constructed to supply water power, still mill privileges have in many instances been granted wherever it was deemed safe to do so without hindrance to the navigation, and much to the advantage of the manufacturing interests of the country, as, for instance, on the Lachine canal, at Montreal and Côte St. Paul, and also at Cornwall. But when the water has to be passed around many locks before reaching the mills, it becomes troublesome at times to regulate the canal, and still keep up the supply to the mills. This has been the case, both on the Lachine and Cornwall canals, where the mills are established at their lower ends. Not so on the Beauharnois canal. Here the water is taken from the dam, at the head of the canal, direct from Lake St. Francis, where the supply is unlimited, and the canal itself is in no way affected by any quantity of water, great or small, that may be used for the mills.

It would be much the same for mills established at Milleroches. Here mill-races could be taken off at both ends of the dam, and run down as far as may be necessary on either side of the river, affording a clear head and fall of 25 to 30 feet, not subject, as at Cornwall, to back water from the main channel of the river, and therefore not liable to be stopped in winter or summer. It is suggested that the dams shall be 25 feet wide at top, in order to form a good road over them. According to the Government plans, there is to be a swing-bridge at Milleroches, so that there will be complete and convenient access to the mills and the island from all parts of the mainland.

From the drawings accompanying this paper, plates XIII. to XV. have been prepared.

DISCUSSION.

Mr. Mohun. The author has so clearly pointed out the causes of failure, and the safety and simplicity of the remedy he proposes, that it appears almost superfluous to protract the discussion.

To the writer it seems surprising that under the conditions described there should have been *only* three breaches in some fifty years, though, as pointed out, constant inspection and prompt repairs have averted many other failures. It would be interesting to learn the average annual expenditure for maintenance of that portion of the canal opposite "Sheek's Island," as compared with other sections.

The objections raised by the author to the original construction have equal weight as against deepening and enlarging the canal by dredging.

As pointed out, if the foundation is unsound, the extra width of bank will give no additional security.

It is too much to expect that no similar sand streaks underlie the present bottom; and in the event of such being reached by the dredge, it seems, in the writer's humble opinion, almost certain that the bank will blow up, which, quite possibly, would be the first intimation of danger.

The author has not only pointed out the faults, but has also suggested the remedy. A remedy which, by making use of the facilities provided by nature, and transforming her from a foe into an ally, promises to prove at once simple, efficient and economical.

The writer fails to follow the author as to the heights of the two dams, if the fall of the river bottom is, as he understands, four feet between them.

As to the interests of navigation during extension, the author clearly shews that they would be better served by the adoption of his plan than by enlarging that portion of the present canal opposite Sheek's Island.

Mr. Macdougall A retrospect of half a century is given to few men in public. A close connection for many years with this large and important public work entitles the criticisms and recommendations of the author to special consideration.

The construction of French (or dry stone) drains under the banks seems to court disaster. The streaks of running sand could only be controlled by a thick layer of puddle laid in a trench as shewn on cross sections 2 and 4. The proposed method of deepening the canal will apparently destroy these trenches, and tend to increase the liability to breaks in the banks. Was it not Brindley who was appealed to, on his sick bed, as to how a similar leak on one of his canals should be stopped? "Puddle it," he said. It seems to the writer that a thick and solid layer of puddle would be the most efficacious method of preventing leakages through these sand streaks.

The author's proposal to use the channel north of Sheek's Island is well worthy of consideration. There seem to be no engineering difficulties in the way, nor are there any tendencies to sudden floods or high water in this portion of the river, to cause anxiety as to the fate of the dams.

Thursday, 21st November.

JOHN KENNEDY, Member of Council, in the Chair.

The discussion of MR. S. KEEFER'S paper on The Cornwall Canal occupied the entire evening.

Thursday, 5th December.

E. P. HANNAFORD, Vice-President, in the Chair.

The discussion of the affairs of the Society occupied the greater part of the evening, and the reading of MR. H. B. SMITH'S paper on The Vancouver Water Works, was postponed to the 19th inst.

Thursday, 19th December.

P. A. PETERSON, Vice-President, in the Chair.

The following having been balloted for, were declared duly elected as:—

MEMBERS.

FREDERICK THOMSON. HENRY YATES.

MAX. A. ZÜRCHER.

ASSOCIATE MEMBERS.

ROBERT MAITLAND HANNAFORD. CLAUDE DE B. LEPROHON.

WALTER R. KIMBALL. EDMUND ALYTH RHYS ROBERTS.

ASSOCIATES.

FREDERICK FAIRMAN. ANDREW F. GAULT.

ALEXANDER GARTSHORE. WILLIAM HENDRIE.

HON. WILLIAM MCDOUGALL.

STUDENTS.

JAMES SHEARER COSTIGAN. FRANK LAMBERT.

FREDERICK WILSON FAIRMAN. DAVID A. MURPHY.

The following has been transferred from the class of Associates to that of Members:—

HERBERT SAMUEL HOLT.

The following have been transferred from the class of Students to that of Associate Members:—

FRANK G. JONAH. HENRY GRATTAN TYRREL.

Paper No. 35.

VANCOUVER WATER WORKS.

By HENRY BADELEY SMITH, M.CAN.SOC.C.E.

INTRODUCTORY REMARKS ON VANCOUVER AND VICINITY.

Previous to the year 1886, the City of Vancouver, British Columbia, had no existence. Where this city now stands, was then a dense, tangled forest of huge fir, cedar, spruce and hemlock; the only evidence of the presence of man being a clearing a few acres in extent, on which low frame buildings, not more than a dozen in number, had been erected, and which was vaguely known to the outside world as Coal Harbour, Gas Town, and the Granville Town Plot.

At this date the Canadian Pacific Railway terminated at Port Moody, a small town at the extreme head of Burrard Inlet, 18 miles from the Gulf of Georgia. The Company, desiring a terminus nearer the open sea, negotiated with the legislature of British Columbia for a grant of land in the neighbourhood of the Granville Town Plot.

The Government, foreseeing that a large city would speedily be built up at the terminus of this great trans-continental railway, were it located on the best attainable site near the sea, voted the grant by a large majority, stipulating only that the extension from Port Moody westward to the lands granted should be constructed and in operation by a stated time. When it became known that the terminus of the railway would undoubtedly be at the Granville Town Plot, population began to pour in so rapidly that, on April 6th, 1886, the Legislature passed an act incorporating the locality as the City of Vancouver.

The population at that date did not exceed two thousand. So great, however, has been the influx of all classes, that at the time of writing, it is estimated on reliable data, that no less than ten thousand souls are contained within the limits of the city.

The City of Vancouver is situated on the south shore of Burrard Inlet, in Lat. 49°, 16′, 31″ N, Long. 123°, 05′, 52″ W, its western boundary being 3½ miles east of the Gulf of Georgia. It is distant from Liverpool on the east 6116 statute miles, and from Yokohama on the west 4991 statute miles. From Montreal to Vancouver is 2905 miles, and from New York, via Canada, to the same point is 3162 miles.

Burrard Inlet is the first harbour of magnitude on the Pacific mainland north of the United States. It is easy of access to vessels of the deepest draught, and safe anchorage can be found in any part. English Bay, the entrance to the Inlet, is 4¾ miles long and 4 miles wide. At its head it divides into two branches,—False Creek on the south, and the First Narrows on the north. False Creek is a narrow arm 4½ miles long, extending due east from English Bay, midway between the North Branch (Burrard Inlet proper) and the south boundary of the City of Vancouver. Being almost uncovered at low water, it is unsuitable for navigation.

The north branch, which leaves English Bay for the First Narrows, extends due east a distance of 14 miles. The width of the Narrows at extreme low water does not exceed 1086 feet, whereas a mile and a half inland it reaches 12,210 feet. Soundings of 120 feet can be obtained at the entrance, and 234 feet at the outlet opposite Vancouver.

The land between Burrard Inlet and False Creek, on which the present Vancouver is built, is for the most part flat, the highest elevation above sea level not exceeding 145 feet. South of False Creek, however, a rapid rise takes place, terminating in a table-land 200 feet above sea level. A few small streams run down from this table-land into False Creek; but these are insignificant, and cannot be utilized for manufacturing or other purposes. The nearest river on the same side of the Inlet on which Vancouver is built, passes 15 miles to the westward.

ORIGIN OF THE CITY'S WATER SUPPLY.

The subject of a good and sufficient water supply for the City of Vancouver, or to write more accurately, for the place now known as the City of Vancouver, was first taken into earnest consideration by Mr. G. A. Keefer, M. Can. Soc. C. E., in June, 1885, nearly a year previous to the incorporation of the city. Mr. Keefer, foreseeing at that early date that the ultimate destiny of the Canadian Pacific Railway was to reach a point nearer the coast than Port Moody, and knowing that the Granville town-site possessed all the requisites for the foundation of a large city, interested himself in obtaining information as to the best source of a water supply for that locality, should the Railway Company decide upon it as the terminus of their system. He speedily ascertained that no supply could be advantageously and economically obtained on the south side of the Inlet, where the city must necessarily be located, no streams or lakes of any magnitude existing in the vicinity.

He therefore directed his attention to the north side of the Inlet, although confronted at the very outset by the fact that, never before in the history of hydraulic engineering had a system of water mains been laid across such a sheet of water as Burrard Inlet, and under such conditions as pertained thereto.

Acting under instructions from Mr. Keefer, the writer placed a fully equipped party in the field, in the winter of 1885-86, and thoroughly examined all the streams flowing into the Inlet immediately opposite the Granville town-site, from the lofty chain of mountains on the north side.

The results obtained from this survey showed that of all the streams available, the River Capilano, falling into the Inlet at the First Narrows nearly opposite the western boundary of the present City of Vancouver, was the most suitable, the discharge being much greater than that of any of the others, and the average fall of the river so great that an initial point for a gravity system of water supply could be obtained within a reasonable distance upstream.

Having decided on utilizing the waters of the Capilano for the supply of the future city, Mr. Keefer experienced no difficulty in obtaining the co-operation of several prominent and enterprising capitalists of Victoria, who were quite in accord with him in the belief that at a very early day a large population would be located at the Granville town-site, and that an immediate outlay for an efficient system of water works would be a remunerative investment.

Accordingly, the extension of the railway to the Granville town-site being an assured fact, and the future name of that locality being definitely decided on as the City of Vancouver, these gentlemen applied to the Provincial Legislature for an act of incorporation of a company, to be known as the Vancouver Water Works Company, and proposing to construct a gravity system of water works, for the purpose of conveying water from a point on the River Capilano, on the north side of Burrard Inlet, to certain specified lots in the New Westminster district on the south side of Burrard Inlet. About the same time, application was made by the inhabitants of these lots for an act of incorporation under the name of the City of Vancouver. Both requests were granted by the legislature on the same day, the 6th of April, 1886.

During the summer of 1886, the writer, acting under instructions from Mr. Keefer, made detailed surveys, definitely locating the point of supply on the River Capilano, and the crossing of Burrard Inlet. In June, 1887, the whole system was finally staked out, and contracts entered into for clearing, close cutting and grubbing. In December,

1887, a permanent Board of Directors was formed, comprising the following gentlemen: President, Capt. John Irving; Directors, The Hon. (now Sir) Joseph W. Trutch, Messrs. R. P. Rithet, G. A. Keefer, Thomas Earle and D. M. Eberts; Mr. J. W. McFarland being appointed Secretary; Mr. D. M. Eberts, solicitor; Mr. G. A. Keefer, M. Can. Soc. C.E., chief engineer; and the writer, Mr. H. B. Smith, M. Can. Soc. C.E., engineer in charge.

THE RIVER CAPILANO.

The River Capilano is a mountain stream of considerable magnitude. Prospectors who have penetrated its cañons, and claim to have reached its source, estimate its length at no less than fifty miles. It rises in the snow-covered mountains of the Howe Sound district, and flows almost due south, emptying into Burrard Inlet at the First Narrows.

Although nothing definite is known as to its source, all accounts agree that its origin is not a mountain lake, but the accumulated waters derived from melted snow and ice falling from the mountain summits. For a distance of seven miles from its mouth, the river has been surveyed. Throughout this distance it flows at the average rate of five feet per second over a bed of granite, basalt and conglomerate boulders. Sand and gravel can be found only in a few sheltered bays. It passes through several cañons of granite and whinstone rock, one of which is only 15 feet wide at its base, 94 feet wide at its top, 500 feet long, and 218 feet deep. Previous to the creation of this cañon, the whole valley to the north must have been one large lake. The wall of rock through which the stream penetrated ages ago, by some sudden effort of the earth's hidden forces, stands like a huge gate at the south end of the valley, the valley itself being but a strip of flat land from 1,000 to 1,500 feet wide, lying at the base of two parallel ranges of mountains, which tower upwards to a height of 3,000 feet. The fall that took place when the river flowed over the summit of this rocky wall must have equalled the Niagara of to-day for depth, if not for volume. Should the City of Vancouver increase to the magnitude predicted, it may be that its people at some future day will cause a dam to be constructed across the narrow gorge, and once again convert this valley into a lake. Vancouver will then possess a reservoir from whence to draw its water supply, which will not be surpassed by any water works system on the continent. These cañons are isolated, standing about a mile apart. Between them the river flows through low lying flats, forming many islands. The immediate banks are but a few feet above the level of the river, and from 100 to 200 feet in width,

the ground on each side rising in terraces until it is merged in the uniform slope of the mountains. Both sides of the river are heavily timbered with the huge trees peculiar to the British Columbia coast, Douglas fir, cedar, hemlock, spruce, balsam and white fir being in abundance. The Douglas fir and cedar grow to an enormous size. One cedar in particular was measured by the writer, and found to be 64 feet in circumference, 4 feet from the ground.

As a source of a city water supply, the River Capilano is an ideal one. No purer water can be obtained from any source than that from this mountain stream, flowing swiftly over a boulder bed, through deep rocky cañons, and along shores as yet uncontaminated by the impurities which follow in the wake of settlement. The supply afforded, being by gravitation, is superior to all other methods, whether by reservoir, direct pressure, or stand pipe, and its permanence is beyond question, careful gauging of the river at the initial point of the system having demonstrated the fact, that at the lowest stage of water the river discharges 440 millions of gallons in 24 hours.

CLEARING, CLOSE CUTTING AND GRUBBING.

The first contract entered into by the Company was for clearing, close cutting and grubbing. This work was done by a local firm at the following prices: clearing, $59.00 per acre; close cutting, $95.00 per acre; grubbing $200.00 per acre, under the conditions of the following specification:—

The pipe track is to be cleared a width of not less than 33 feet, and all timber and brush, not required for the purposes of the work, piled up and burned, as in clearing land for cultivation.

The dam site is to be cleared in the same manner, and to such limits as may be directed by the engineer.

Whenever embankments, occurring on the line of pipe track or tramway, are less than two feet in height, all the trees, stumps and brush immediately under the embankment, are to be cut close to the ground, and whenever the embankments are from two to four feet high, they shall be cut within six inches of the ground; but when the embankments exceed four feet in height, chopping as for ordinary clearing will be allowed.

Grubbing shall be performed under the seats of the embankments occurring on the line of pipe track, or tramway, that do not exceed one foot six inches in height, and also all excavations for pipe track, tramway and dam embankment, less than three feet deep. The stumps and roots from the grubbing shall be removed to such places as directed.

No Chinese are to be employed, directly or indirectly, on the above works.

THE DAM.

The point on the river selected as the source of supply is at a distance of 6½ miles upstream from its mouth, where the river is confined to one channel, and the banks on either side are sufficiently high to admit of the construction of a dam.

The locality selected is the only point from the river's mouth upwards where a dam could be safely and economically constructed, and give at the same time a sufficient head to overcome the elevation of the high flats 3½ miles below it.

By reference to Plate XVI, which shews the dam site and its vicinity, it will be seen that immediately south of the site the river is divided into two wide channels.

Still further south, all the way to the cañon below, it is divided into three and even four channels. Similarly, north of the dam site, the river has two branches separated by a large, low, flat island. This island is completely covered at high water, making the river at that stage no less than 830 feet wide.

The cross section of the river at the dam site at low water gave a current of 4½ feet per second, a width of 100 feet, and an extreme depth of 3 feet, the difference of level between low and high water being 6 feet. It has been subsequently ascertained, however, that during occasional floods the water rose much higher, and covered the level flat on the north side to a depth of 2 feet. This flat stands at an average level of 12 feet above low water. The bed of the stream consisted of large granite boulders, closely packed together, small stones and coarse gravel filling up the interstices. The channel of the river in ordinary floods was 210 feet wide.

On the north shore the immediate bank is 12 feet high, and extends at the same level a distance of 140 feet inland. A sudden rise then takes place, terminating in another flat 40 feet above low water, and which stretches to the base of the mountains.

On the south shore, the bank rises abruptly to a height of 22 feet above low water, and continues at that elevation for 200 feet. It then rises rapidly in terraces till it reaches the mountain side hill. The high land on the north shore trends to the northward immediately west of the dam, and that on the south to the southward, immediately east of the dam.

The dam site lies directly between these two high points. The contract for the construction of a stone-filled timber dam at the point selected was let on the 24th of January, 1888, to Messrs. H. F. Keefer and D. McGillivray of Vancouver, and was most satisfactorily completed by them on the 18th of April following. The difficulties encountered by the contractors in carrying out this work were of no ordinary character. Inasmuch as it was the initial work of the system, and located in a wilderness in which no roads existed, all supplies, tools and machinery were of necessity packed to the works on the backs of mules. The season was mid-winter, and unusually inclement. Chinook winds and heavy rain-storms, melting the snow on the mountain summits, caused frequent freshets, in which the river would rise from 6 to 10 feet in a few hours time.

The formation of the banks in the vicinity did not admit of the river being temporarily diverted, except at enormous cost. The foundations of the structure had therefore to be excavated, and the first courses laid in from 3 to 4 feet of swift running ice cold water.

Plate XVII is a reduced copy of the working plan of the dam. It will be seen that the structure is of continuous cribbing, stone filled, planked and sheet piled. It consists of three principal parts, viz., the north abutment, the tumbling way, and the south abutment.

The north abutment is located well inland, owing to the tendency of the river in high floods to over-run its channel, and spread over the low lying land in the vicinity. For the purpose of description it may be subdivided into the following heads: The abutment proper, the well chambers, the settling pond, the pipe outlet, and the north wing.

The abutment proper is a right rectangular prism 41′. 2″ × 20′ × 18′. 9″, constructed of round timbers, laid in alternate courses of cross ties and longitudinals, dove-tailed at the angles, and forming 28 cribs, which are filled up with heavy stone filling and coarse gravel, the latter being rammed into all interstices between the stones and under the timbers. A space equivalent to four cribs, in the exact centre of the abutment, is floored and walled, from the foundation upwards, with double 2″ planking over-lapping. A perfectly watertight chamber 10′. 6″ × 7′. 10″ is formed. This chamber is subdivided into two smaller and equal ones by parallel walls, 4″ apart, of double 2″ planking overlapping, and placed at right angles to the length of the main chamber. These constitute the well chambers, by means of which the water from the reservoir formed by the dam is conveyed into the mains. An influent conduit of double 2″ planking overlapping, 15′ 5½″ long, and of area sufficient to admit a larger volume of water than can be discharged by

the mains, connects the first of these chambers with the settling pond, and consequently with the reservoir in front of the dam. In the 4″ space between the double central walls, close to the floor of the chambers, are placed double fish screens of the same area as the influent conduit, and so arranged that they can be easily removed, one at a time, for the purpose of cleaning. The first or outer screen is coarse, being of No. 12 copper wire, woven into meshes one inch square. The second or inner screen is finer, being of No.15 copper wire, 6 meshes to the inch. The rear of the second chamber is pierced exactly opposite the fish screens to admit of two bevelled 22 inch rivetted steel pipes, the mouths of which are opened or closed at will by means of timber gates sliding in vertical uprights attached to the walls of the chamber.

Two trap doors cover the top of the chambers, and over all, resting on the top courses of the abutment, is built a compact water-proof shed 12′ × 13′ × 13′. This shed serves for a tool house, as well as effectually preventing the access of strangers to the gates which control the mains.

In front of the influent conduit is a triangular shaped settling pond, measuring 15½ feet at the base, 16 feet from base to apex, and 14′ 2″ deep. It is constructed of longitudinal timbers and cross ties, laid one above the other, the whole being firmly bolted to the face of the abutment. At the apex the ends of the longitudinals are dressed, so as to fit closely, and bolted together. The triangular space between the apex and the apex cross ties is filled with large boulders, for the purpose of giving weight to the structure, and retaining it in position.

At the base of the pond, the entrance of water into the influent conduit is controlled by means of a timber gate, sliding in vertical runners bolted to the sheet piling on the face of the abutment. Immediately behind this gate covering the mouth of the conduit is placed a cast iron grating with 4-inch openings. The water from the river has free access to the settling pond through the spaces between the longitudinal timbers of the walls. The main object of its construction is to prevent logs and floating debris from accumulating in front of the influent conduit. It will thus be seen, that, in order to reach the mains, the water must first enter the settling pond, then pass through the iron grating at the mouth of the influent conduit, then, by means of that conduit, enter the first well chamber, then through the double fish screens in the central walls into the second chamber, and finally into the mains in the pipe outlet.

The pipe outlet at the rear of the north abutment is a crib continuation of that abutment, serving as a protection for the mains against the action of the water flowing over the tumbling way, until a safe point

is reached on the flat below. It is 138 feet long, 15 feet 3 inches wide, 10 feet high on the side facing the river, and 6 feet on the land side. It has three parallel rows of longitudinals supported on cross ties, the two outside rows, or the rows nearest the river forming cribs 4'. 9" × 3'. 5" × 10', which are heavily loaded with boulders. Between the cribs and the third row of longitudinals on the land side, is a space 8 feet wide, in which the mains leading from the well chambers are laid.

Provision is made for two mains, but only one is in use at present, the other being capped at its lower end, and closed at its mouth by means of its gate in the second well chamber. The space containing the two mains is filled with coarse gravel, well packed. Above the filling is a covering of 15 inch logs close laid.

In the immediate rear of the abutment the timbers of the pipe outlet are continued upwards in steps to the top of the abutment, forming a "lean to," which prevents the water, flowing over the tumbling way, from flooding the top of the pipe outlet. The "lean to," as well as the entire face of the pipe outlet, is planked with 3 inch planking, sunk 3 feet below foundation level.

The low lying porous nature of the ground on the north side of the river rendered necessary the construction of an extensive land wing, with deep foundations. This wing is 155 feet long, and 10 feet wide. The first 20 feet out from the abutment is 16 feet 11 inches high, and is in reality part of the abutment proper, its longitudinals being a continuation of the longitudinals of that structure. The remaining 135 feet, being built on higher ground, has a uniform height of 7' 9" Both portions are built in rows of parallel longitudinals, 3 in number, and in lengths of 31 feet, supported on cross ties 10 feet long, and 5 feet apart. These form 62 cribs, which are filled with stone and gravel as previously described.

The connection between the wing and the high land at its extremity is protected by a gravel enbankment, extending 57 feet along the face of the wing. This embankment is made of picked material, and effectually prevents all seepage round the end of the wing. The face of both abutment and wing is protected from leakage by a double row of sheet piling, the lower ends of which are embedded in a concrete trench sunk 3 feet below foundation level. The inner sheet piling is 2 inches thick, while the outer and overlapping piling is 1 inch.

The main body of the dam, technically named the Tumbling Way, is 165 feet in clear length, 41' 2" broad, and 13' 9" high in the deepest part of the original channel of the river. Great difficulty was experienced in excavating foundations for this portion of the dam. At

first an effort was made to partially divert the river by excavating a new channel, between high and low water mark on the south shore, the intention being, if this succeeded, to excavate the foundations and build the sub-structure up to the toe of the front slope; then to return the river back to its original channel, allowing it to flow through the row of horizontal openings provided in the design of the structure for that purpose. It was found however that the bed of the proposed diversion, being entirely composed of loose boulders, was too porous to admit of the water being confined within the excavation; and as, at that time, no clay, fit for puddling, was known to exist in the near neighbourhood, this project had to be abandoned. The method then adopted and which proved successful, though carried out under great difficulties, was as follows:—

Both abutments having been partially constructed, the foundations for the end divisions of the tumbling way were excavated as far as possible from the abutments towards mid-channel. As much of the structure as the excavations could contain was rapidly built up, and loaded with stone filling. An embankment of gravel and sand was then run out from each extremity, meeting about 20 feet up stream and forming a V, the apex of which divided the current of the river, and forced it through the horizontal openings in the sections already built. This had the effect of leaving still water three feet deep behind the embankment, and as this could not be removed, nor lessened in depth, the foundations were excavated and the middle section built under these exceptionally difficult circumstances.

The sills of the north and south sections are on the same level, while those of the middle section in the deepest part of the river bed are 2′ 2″ lower. The cross sections of the three portions are similar. Plate XVII shews that of the middle section.

The ground sills, 10 in number, in lengths of 32 feet, are placed at right angles to the stream, at distances varying from 5′ 5″ to 6′ apart, the distances varying in order to secure a row of longitudinals under each vertical angle of the surface of the tumbling way. Above the sills and at right angles to them are placed a row of cross ties parallel with the stream, each 53 feet long, and from 5′ 8″ to 6′ apart. These project 11′ 10″ to the rear of the main body of the dam, resting on two of the sills of the ground course. The spaces between these projections are filled in with round timbers laid close. A solid close laid platform, to the rear of the main body of the tumbling way, is thus formed, which serves to dissipate the force of the water flowing over the tumbling way before it reaches the bed of the river. The next or third course

consists of eight longitudinals, above which, on the fourth course, are the horizontal openings previously mentioned. These are 28 in number, five feet wide, 12 ins. deep, and extend entirely through the structure from its upstream face to the open river in the rear.

They are formed by flooring the spaces between the cross ties of the 4th course with double one inch planking, and close laying the longitudinals of the 5th course to serve as a covering. Above the 5th course the longitudinals and cross ties are so arranged that the front face slopes upwards to the ridge at the rate of 2 '3½" to 1'. The longitudinal which constitutes the ridge is placed at a horizontal distance of 17' 2½" from the front face, and is at an elevation of 415 feet (surface planking not included) above high water mark of Burrard Inlet. The rear slope extends downwards from the ridge at the same rate as the front slope, and terminates in a level bench 12 feet wide.

In the tumbling way there are 196 cribs, formed by the intersections of cross ties and longitudinals. Especial care was exercised in filling these cribs. As each course was completed, the largest boulders obtainable were placed in the cribs by hoists. The spaces between were filled up with smaller stones and coarse gravel, the latter being rammed into every crevice. In excavating the foundations, certain huge boulders, which were found to be firmly anchored in the river bed, were blasted into a columnar shape, so that the bed sills and cross ties when laid would enclose them. These not only served as stone filling, but also securely locked the whole structure to the bed of the river in a much more substantial manner than any artificial means.

The whole surface of the tumbling way is covered with 3 inch planking, jointed and laid close. The upper half of the front slope, being exposed to floating logs, is laid double. The vertical part of the front face is protected by 1" and 2" sheet piling, embedded in a concrete trench three feet deep, extending over the whole length of the structure.

Inasmuch as it was necessary to keep the horizontal openings open until the whole dam was completed, the placing of this sheet piling was done in two operations.

The lower portion of the piling below the level of the floor of the openings was placed in position in the usual manner, the tops being dressed to a uniform level. A longitudinal 12" by 3"plank, extending over the whole length of the tumbling way, was spiked to the tops of this sheet piling, projecting one inch above, and forming a groove into which the upper sheet piling would fit when placed in position. When the proper time arrived to close the openings, a sufficient number of men were ranged along the toe of the front slope, provided with the

proper lengths of sheet piling, spikes and hammers. On a given signal each plank was pushed home into the groove below the openings, and the necessary spikes driven into the top ends. It required only five minutes to complete the whole operation, and by that time, the water in front had not risen above the toe of the front slope.

Immediately in front of the tumbling way is an apron of brush, gravel and boulders. This apron extends from the settling pond in front of the north abutment clear across the face of the tumbling way to the gate of the sluiceway. In cross section, it begins at a point halfway up the front slope, and extends horizontally a distance of 9 feet. It then slopes down to the bed of the river at the rate of 3 to 1.

The south abutment, being partially let into the high land, required no wing extension. Properly speaking, it consists of three distinct parts, viz., the abutment proper, connecting with the tumbling way; the land abutment, connecting with the shore; and the sluiceway, which lies immediately between the two. The foundations of all three are on the same level as those of the north abutment, and being above low water mark were excavated without trouble.

The abutment proper is a rectangular prism 41′ 2″ × 15′ × 18′ 9″ constructed of longitudinals and cross ties in alternate tiers, bolted together and dove-tailed at all four corners. As in the north abutment, the longitudinals of the tumbling way at regular intervals project into the abutment, and are securely bolted to it, thus forming an absolute and immovable connection between the three structures. In this abutment, there are in all 21 cribs, each 5′ 8″ × 4′ 7″ × 18′ 9,″ filled and rammed as previously described. In the rear of the abutment is a "lean to," 31 feet long, and tapering from 15 feet at the abutment to 11 ft. 7 ins. at its extremity. This also is a stone filled crib structure, the object of which is to prevent any scouring that might take place, by guiding the water flowing over the tumbling way beyond the rear of the abutment, and into the original channel of the river. It may be here mentioned that one year after the completion of the dam, a large scour did take place in the angle formed by the foundation courses of the "lean to" and the rear platform. During a sudden freshet the bed of the river at this point scoured out to a depth of 4 feet below foundation level. The end cribs of the "lean to" were completely undermined, the stone filling carried away, and the timbers left unsupported. A somewhat similar occurrence had taken place a few months previously at the angle formed between the rear platform and the pipe outlet on the north side. The latter was readily repaired by filling in and constructing a triangular extension of the rear platform

as shewn in drawing. In this case the extension could be easily bolted to the existing platform and the pipe outlet. But in the case of the first mentioned scour it was quite different. The "lean to" being an addition to the rear of the abutment and not a part of it, timbers extending from its extreme end to the rear platform, so as to cover the large scour made, and prevent further injury, would have been insecure.

Instead, therefore, the damage done was repaired by refilling the scour with a mixture of large boulders and concrete, the latter being in the proportion of 1 part of pure cement to 7 of coarse gravel and sand.

Over this filling, and extending three feet beyond the rear of the "lean to," was placed a covering of almost pure cement, 1 foot thick. Twenty-one barrels of Portland cement, each weighing 400 lbs., were used in making these repairs. The total length of the abutment and "lean to" combined is 71 ft. 11 ins. It therefore projects beyond the rear of the tumbling way, a distance of 31 feet. Both sides and rear, as well as the top of the "lean to," are planked with 3″ planking laid close.

The sluiceway is 73 feet long and 14 feet in clear width. From wall to wall it is 15 feet wide, and at the upstream end is the full height of the abutments. Both walls and face are planked with 3″ planking, laid close. It is opened and shut by means of a stop log gate, consisting of 17 stop logs 17′ 4″ × 12″ × 12″, placed horizontally one above the other, each capable of being moved vertically in a groove formed by vertical 12″ × 12″ uprights, let into the walls of the abutments on each side. On the upstream face the uprights are single, connected at the base by a 12″ × 12″ sill. Behind the stop logs the uprights are double, while midway between is a triangular truss of framed 12″ × 12″ timbers, planked with 3″ planks, the sill of which extends back from the rear of the stop logs, a distance of 17½ feet, and is securely bolted to the ground flooring. The floor sills beneath the truss are close laid on a concrete bed, forming a solid apron, on which the force of the water falling over the gate when partially open is spent previous to discharge into the channel of the river. From the end of the truss to the outlet of the sluiceway, sills are laid four feet apart, extending underneath and bolted to the sills of the walls, or in other words to the sills of the abutments on each side. The two sills immediately behind the rear uprights of the gates, and the three sills at the end of the close laid flooring are squared 12″ × 12″ timbers, 43½ feet long, and pass under the whole width of both abutments. Similarly two caps 43½ feet long are laid across the top of the sluiceway, behind the rear uprights of the gate. These sills and caps are securely bolted to every intersecting timber of

the abutments on each side of the sluiceway, thus making a solid union between the three parts.

Above the stop logs is a powerful windlass, with supports on each abutment, the roller being directly above the stop logs. The upper surface of each stop log is provided with a wrought iron ring at each end, the stop log immediately above it being grooved on its under face, so as to admit the rings, when the stop logs are in position, and the gate is closed. The extremities of the chains connected with the windlass are provided with clutches which can be readily guided so as to hook on to the rings, when it is required to open or close the gate.

The sluiceway abutment, or that portion of the south abutment which connects directly with the land, having to withstand much less pressure than other portions of the dam, is not of uniform height, but is built in steps. At the upstream end it is of equal height, 18 ft. 9 ins., with the main portion of the abutment on the other side of the sluiceway, and 13 feet wide, while at the extreme rear, the height is only 5 feet, and the width 8 feet. It consists of 16 separate cribs, loaded with stone and gravel, as previously described.

The whole abutment, including the sluiceway, is protected in front by 1″ × 2″ sheet piling overlapping and imbedded in concrete, as in the case of the tumbling way and north abutment. This concrete is in the proportion of 1 part of cement to 5 of gravel and sand. The manner of its preparation was as follows: moist gravel of suitable nature obtained from the river bank was deposited on a plank platform 10 feet square. This was thoroughly worked with shovels, and all stones larger than 1½ inch diameter eliminated, leaving the mass spread over the platform about 9 inches deep. The proper proportion of cement was then spread over the gravel, in a dry state. Very little water was used, the moisture in the gravel being sufficient for the purpose. Six men with shovels then energetically worked the whole mass, shovelling from the outside edges towards the centre. When satisfied that the mass had been completely turned over once, it was flattened out on the platform, and again turned over in the same manner. This operation was repeated three times, the mixture being then considered fit for use.

The concrete trench mentioned above, extends along the whole face of the dam below the level of the sills, forming a perfectly watertight connection between the foundations and the bed of the river, through which no seepage can take place. Seepage round the extremities of the abutments, where they penetrate the banks, is prevented on the north side, as previously stated, by a gravel embankment. On the south side the same purpose is served by a hand-laid stone wall, built in the

angle formed by the extremity of the abutment and the natural bank of the river, fine gravel and earth being filled in behind and well rammed.

The reservoir created by this dam is, in the high water season, 380 feet wide by 700 feet long, and contains approximately fourteen millions of gallons.

At low water the elevation of the water flowing over the crest of the tumbling way is 483 feet above the lowest depression in the pipe line, 417 feet above the lowest level in Vancouver, 317 feet above the average, and 201 feet above the highest. These elevations correspond to a maximum pressure of 210 lbs., an average pressure of 138 lbs., and a minimum pressure of 87 lbs. per square inch.

The wrought iron drift bolts used were of $\frac{7}{8}''$ and $\frac{3}{4}''$ round iron, and of lengths varying from 12″ to 32½″. Spikes for 3″ planking were 6″ long, weighing 11 per pound, and nails for 1″ planking were $4\frac{3}{8}''$ long, weighing 19 per pound.

From the above description it will be seen that the extreme length of the dam, from land connection to land connection, is 384 feet, the clear tumbling way 165 feet, supplemented by an additional 14 feet of sluiceway, when required, and the breadth of base, not including rear platform 41 ft. 2 ins.

The total cost amounted to $15,039.26.

ROUTE OF THE MAINS.

The country traversed by the mains, from the dam to the central point of the city was, from a hydraulic point of view, of a very rough nature, and presented many engineering difficulties.

From the dam, for a distance of 12,716 feet in a downstream direction, the ground passed over is a gradually descending flat, the total fall in this distance being 164 feet. The flat is a narrow strip of land, composed of hardpan and granite boulders, lying between the base of the mountains on the one side and the river on the other. At two points, the river, in former heavy floods, has invaded the flat and the adjoining side hill, scouring off portions 500 feet in length, and leaving a bare boulder bottom only a few feet above the low water level of the river. Several streams running down from the adjoining mountains, intersect the flat at right angles. Two of these are of considerable size, one being 47 feet, and the other 212 feet from bank to bank. Both flow over rough boulder bottoms.

At the termination of the flat is the rock wall through which the river has cut the deep cañon previously described. Owing to the rug-

ged nature of the walls of the cañon, it was not deemed advisable to carry the mains along its face, and its great height prevented their being laid over the summit. A tunnel therefore was rendered necessary. This tunnel is 280 feet long, 4 feet wide, and 6 feet from floor to centre of roof. In cross section, the walls rise vertically 4 feet from the floor, and are surmounted by a semicircular roof of 2 feet radius. The floor elevation is 27¾ feet below the crest of the dam.

Inasmuch as the hydraulic grade line of the whole system passes considerably below the floor of the tunnel, it was necessary that the main, from the dam to the tunnel, should be of larger diameter than that from the tunnel to the city. It having been decided that the discharge of a 16 inch main was necessary for the city's supply, a 22 inch main is laid between the dam and tunnel, connecting in the centre of the tunnel with the 16 inch main. The total length of the 22 inch main is 13,530 feet, the total available head 29 feet, and the discharge at the tunnel 5,853,600 U. S. gallons in 24 hours.

The 16 inch main, connecting with the 22 inch main at the centre of the tunnel, for the first 8000 feet of its length, passes over a rough, irregular side hill, composed of earth, gravel and boulders. The sinuosities of the side hill are closely followed, all great vertical depressions or elevations being avoided. In one instance, 1400 feet below the rock tunnel, where the side hill juts out in the form of a steep "Hog's back," it was found expedient to pierce it with a timber lined tunnel, 108 feet long, 4 feet wide, and 6 feet high.

At the termination of the side hill, a series of flats, composed of hardpan, gravel and boulders, descending in broad terraces is reached. These are followed by the 16 inch main to ordinary high water mark of Burrard Inlet, the total distance from the centre of the tunnel being 19,320 feet, and the total fall from the floor of the tunnel 388 feet.

At Burrard Inlet the 16 inch main is divided by a cast iron Y breech into two branches of 12″ diameter. One 12 inch branch has already been laid across the Inlet, and preparations are in progress for the laying of the second, which will take place at an early date. Plates XVIII and XIX shew plan and profile of the First Narrows of Burrard Inlet, at the point selected for crossing. It will be seen that this is at the narrowest part of the Inlet, where the tidal current runs with the greatest velocity. It would naturally be supposed that the greatest depth of water would be obtained here, but this is not the case. The bed of the Inlet at this point, being soft sandstone rock, partially covered with mud, gravel and cobblestones, forms a broad flat ridge, extending from shore to shore. The greatest depth of water on the

summit of this ridge at extreme low tide is 56 feet, gradually increasing on each side till soundings of 120 feet and over can be obtained.

In extreme low tides the width of the crossing is 1086 feet. These tides, however, are very rare, occurring in May and June. In ordinary tides the width at low water is 1237 feet, and at high water 2140 feet. At extreme high water, which occurs in December and January, the width is 2680 feet.

The north shore is extremely low and flat. From low water mark for a distance of 6750 feet inland, the total rise does not exceed 63 feet. Between high and low water mark, the surface covering consists of cobblestones, small boulders, and coarse gravel, underneath which is a stratum of hard pan overlying sandstone rock. The south shore rises abruptly at high water mark to a height of 12 feet, terminating in a level flat, which extends some distance inland. Immediately west of the crossing on this side of the Inlet, is a steep rocky headland, which rises to an elevation of 216 feet above sea level.

This is the highest elevation within the limits of the city of Vancouver, and may at some future day be utilized, as the site of a level reservoir, of sufficient capacity to supply the city for 20 or 30 days. Between high and low water marks on the south shore, and for nearly three-quarters of the distance across the Inlet, the surface formation is soft yellow sandstone rock, which, when blasted and exposed to the air, rapidly disintegrates. The contour of the bottom is an almost perfect curve, the value of which railway engineers would express as $2\frac{1}{2}$ degrees.

Skilled divers made three different examinations of the bottom, and reported fully thereon, agreeing with each other in every particular.

The substance of their reports was to the effect that no crevices existed in the rock ledge on the pipe line, or in its neighbourhood, and that the bottom from shore to shore was perfectly smooth and free from boulders of any magnitude.

These reports were verified to a certain extent, by soundings taken by the writer, at intervals of five feet apart, the lead, which weighed 15 lbs., never being allowed to leave the bottom all the way across.

The greatest depth recorded is, as before stated, 56 feet at low water, increasing to $70\frac{1}{2}$ feet at high water. The "Bore" or tidal current varies from $4\frac{1}{2}$ to 9 miles per hour, the greatest velocity occurring in the out-going tide, $2\frac{1}{2}$ hours after low water. In a volume of water like that flowing from the broad basin of Burrard Inlet through the restricted channel of the First Narrows into English Bay, this velocity of 9 miles per hour is terrific in its effects on any body opposing it.

Some idea of its force may be gathered from the fact that a new 9 inch manilla hawser of 20 tons ultimate tensile strain, which, in the preliminary operations of laying the submerged mains, was stretched across the inlet, was snapped like pack thread by being suddenly lifted to the surface, and allowed to float on it.

South of Burrard Inlet, at high water mark, the single 12 inch main connects with a Y breech similar to that on the north side. A 16 in. main leads out from this breech, passing over a uniform boulder and gravel flat, known as Stanley Park, the greatest elevation of which above sea level is 73 feet. South of Stanley Park, at a distance of 5041 feet from Burrard Inlet, is a long, narrow, shallow bay of Burrard Inlet, known as Coal Harbour. This bay lies directly south of and parallel to, the First Narrows. The extreme length from east to west is 6720 feet. The entrance to the bay is 3,730 feet wide. This width gradually decreases till the head is reached at a distance of only 1,500 feet from English Bay, and separated from it by a low lying strip of land, the highest elevation of which above sea level is not more than 17 feet. The bottom is of soft mud, thickly studded with boulders. Half a mile from the head of the bay, the shore on each side cuts out in long narrow promontories, leaving a waterway 870 feet wide at high water, and 250 feet at extreme low water. This is the point selected for the crossing of the 16 inch main. The bottom is of uniform contour, and consists of tenacious mud and small boulders. The greatest depth at low water, which occurs in mid-channel, is 5 feet.

Immediately south of Coal Harbour the City of Vancouver is reached. The 16 inch main is continued along the graded streets to the centre of the City, a distance of 39,211 feet from the centre of the tunnel, or almost exactly 10 miles from the well chambers of the dam.

The total fall from the level of water in the reservoir at the dam to the termination of the 16 inch main is 384 feet, and from the floor of the tunnel to the same point 355 feet. The total available discharge is 5,103,000 U. S. gals. in 24 hours.

TRENCHING, TUNNELLING, ETC.

South of Burrard Inlet, all works of excavation, refilling, culvert building, etc., were done by the company by day labor. North of Burrard Inlet, between the First Narrows and the dam, such works were done by Messrs. H. F. Keefer and D. McGillivray, of Vancouver, under a lump sum contract, based on a table of quantities furnished by

the Company. The trenches were excavated to regular grades, the average depth for 12″ pipes being 3′ 6″, for 16″ pipes, 3′ 10″, and for 22″ pipes 4′ 4″, this gave a covering over all pipes of not less than 2′ 6″, an amply sufficient depth in the climate of Vancouver, frost never being known to penetrate the soil deeper than 14 inches. When the nature of the ground was uneven, and the grade line laid down gave excavations less in places than these depths, the difference was made up by embankments, 3 feet wide on top, with slopes of 1½ to 1. In certain small gullies, embankments 6 feet wide on top, were built under the mains, instead of timber trestling, there being danger of bush fires during the summer months. The mains on top of these embankments, and also under all streams, are protected from injury by being enclosed in timber culverts. (See Appendix, p. 358.)

ADVANTAGES OF STEEL OVER WROUGHT AND CAST IRON MAINS.

Previous to describing the rivetted mild steel mains used by the Vancouver Water Works Co., it may be of interest to trace the origin of steel pipes, and exemplify the many advantages possessed by them over cast iron pipes.

Up to the year 1845, cast iron was in universal use for the manufacture of water pipes; but in that year, Mr. Jonathan Ball invented and laid in Saratoga, N. Y., a wrought iron pipe, coated inside and out with hydraulic cement. This is the first instance on record in which wrought iron water pipes were laid on this continent. Owing to the great saving effected by this invention, it rapidly rose in favour, and was adopted by many cities in the Union. It was soon, however, discovered that these pipes required to be laid on a perfectly solid and unyielding foundation. If laid on made ground, the slightest settlement caused the cement linings to crack and leakage took place. The method of lining and laying in the trench was cumbersome, and could only be employed to advantage near the centres of civilization, where transport was cheap and labour abundant. When it was required to carry long lines of water pipes over mountainous country, in wildernesses entirely unsettled, and without roads or means of conveyance, engineers were confronted with the task of devising another and still more economical pipe. In California and the Pacific States of the Union, this problem was successfully solved by the invention of asphaltum coated rivetted wrought iron pipes. The cheapness of construction of these pipes, and the facility with which they could be handled, and more especially in the mining districts, brought them at once into general use. In design and construction they are exactly similar to the rivetted mild

steel mains described further on in this paper. Between 1870 and 1885, the Risdon Iron Works Company, of San Francisco, furnished various water and mining companies with over 150 miles of these pipes varying in diameter from 12 to 52 inches. Among the more notable examples may be mentioned the following:

SPRING VALLEY WATER WORKS CO.—36 miles of pipe from 18 to 52 inches diameter, and from $\frac{8}{100}$ to $\frac{3}{8}$ in. thick.

THE VIRGINIA AND GOLD HILL WATER WORKS CO.—3 miles of pipe $11\frac{1}{2}$ inches diameter, and from $\frac{1}{4}$ to $\frac{3}{8}$ in. thick. This main crosses a deep valley lying between its point of supply at Lake Marlette and Virginia city. The bottom of the valley is 1750 feet below the level of the lake. Therefore this main is subject to a constant static pressure of 750 lbs. per square inch at its lowest point

THE WHITE PINE WATER WORKS CO.—2 miles of pipe, 12 inches diameter, $\frac{12}{100}$ to $\frac{5}{16}$ in. thick.

THE PORTLAND WATER WORKS CO.—$4\frac{1}{4}$ miles of pipe, $30\frac{1}{2}$ inches diameter, and $\frac{17}{100}$ in. thick.

THE CHEROKEE FLAT MINING CO.—3 miles of pipe, 30 inches diameter, and from $\frac{8}{100}$ to $\frac{3}{8}$ in. thick.

The great success of asphaltum-coated rivetted wrought iron pipes led to still further researches. Manufacturers of water pipes directed their attention to the adaptability of mild steel for hydraulic purposes, and arrived at most gratifying results.

The writer, in seeking information on this subject, received from Messrs. Duncan Bros., of London, England, a pamphlet on mild steel mains, of which only a few copies were published by that firm for private circulation. The following extracts, giving a comparison between mild steel, wrought iron, and cast iron for water mains, may be of interest:

"Scientific investigation proved that in addition to being more ductile, it (wrought iron) had greater tensile strength than cast iron, the relative tensile strengths of cast iron and wrought iron being approximately 1 and 2.7. Mild steel is refined wrought iron, being nearly pure metallic iron, and when rolled into plates its strength compared to cast iron is as 4 to 1. In consequence of its strength and ductility, it is eminently adapted for all purposes to which cast iron has been formerly applied.

"With regard to strength, the ultimate tensile strength usually mentioned in specifications for cast iron pipes is 18,000 lbs. per square inch mild steel, however, is now made with an ultimate tensile strength of 72,000 lbs. per square inch. It follows, therefore, that if pipes are made of steel plates of the same thickness as would be employed in cast

iron, they are approximately four times as strong. The actual strength is not exactly four times, because it is not customary to calculate resistance to internal pressures with the same co-efficient or factor of safety for both materials.

"The factor of safety usually employed for cast iron is 10, that is to say, the working strength of the material is taken as only one-tenth of the actual strength, which, in the case of pipes, means that if the internal working pressure is to be 100 lbs. per square inch, the strength of the pipes is calculated to resist 1000 lbs. per square inch. For wrought iron, the factor is 6, and for mild steel 5. The reason for the differences in the factor of safety, is because iron and mild steel are more homogeneous, and thus more reliable than cast iron.

"The impurities which are present in cast iron are of less specific gravity than metallic iron, and consequently the specific gravity of the mixture called cast iron is less than that of pure metallic iron. Mild steel is the nearest approach to pure metallic iron, which commerce and science combined have yet produced on an extensive working scale. The average weights of the metals are:

Cast Iron.	*Wrought Iron.*	*Mild Steel.*
450	480	489.6

lbs. per cubic foot; the average weight of water is 62½ lbs. per cubic foot; therefore the specific gravities average

Water.	*Cast Iron.*	*Wrought Iron.*	*Mild Steel.*
1	7.20	7.68	7.83

TABLE OF RELATIVE THICKNESS FOR EQUAL STRENGTH.

	Cast Iron.	*Wrought Iron.*	*Mild Steel.*
Weight of plate in lbs., per sq. ft. 1 inch thick	37.5	40	40.8
Tenacity per square inch	18,000	48,600	72,000
Relative strength for equal thickness	1	2.7	4
Factor of safety	10	6	5
Relative strength due to factor of safety	1	4.5	8
Reduction in strength due to rivetted joints	—	30 p.c.	30 p.c.
Relative strength after reduction for rivetted joints	1	3.15	5.6
Relative thickness for plates of equal strength	1	0.3174	0.1786

TABLE OF RELATIVE WEIGHT FOR EQUAL STRENGTH.

	Cast Iron.	*Wrought Iron.*	*Mild Steel.*
Thickness of plate in inches, 40lbs. weight per sq. ft..	1.066	1.00	0.9804
Relative strength for equal weight	1	2.533	3.678
" " due to factor of safety.....	1	4.22	7.356
Relative strength after reduction for rivetted joints	1	2.955	5.149
	Cast Iron.	*Wrought Iron.*	*Mild Steel.*
Weight of plain cylinders of equal strength	1	0.3384	0.1942
Increase in weight of pipes due to joints.....	5.8 p.c.	15 p.c.	15 p.c.
Relative weight of pipes of equal strength.....	1	0.3678	0.2111

"The relative thickness for plates of equal strength for materials of the ultimate tenacity under consideration are given on the last line of the first table. In the next table, the results obtained shew the relative weights of pipes of equal strength, having socket and spigot joints, made from materials of the ultimate tensile strength specified.

"Applying these results to an ideal case, we find that, if it is specified that cast iron pipes, to stand 300 feet working head of pressure, and 24 inches internal diameter, are to be $\frac{7}{8}$ inch (= .875) thick, then wrought iron pipes of the same diameter would be .875 × .3174 = .2778 inches thick, and mild steel pipes would be .875 × .1786 = .1563 inches thick or say $\frac{7}{8}$ in., $\frac{9}{32}$ in. and $\frac{5}{32}$ in. thick respectively, for equal internal working pressures.

"Then again, if one mile of 34 inch cast iron pipes, $\frac{7}{8}$ inch thick, made up of pipes in 12 feet lengths, weighing 24.8 cwt. each length, weighs 545.6 tons, the corresponding weight of one mile of wrought iron pipes will be 545.6 × 0.3678 = 200.6 tons.

and one mile of mild steel 545.6 × 0.2111 = 115.2 tons.

"These results shew that for equal diameters, 24 inches, equal working pressures of 300 feet and equal lengths of one mile, the weights are respectively:

Cast Iron.	*Wrought Iron.*	*Mild Steel.*
545.6	200.6	115.2 tons.

The price per ton of mild steel pipes averages about 4½ times the current price of cast iron pipes; as the relative weights for equal strength are as 1 : .2111, it is therefore apparent that the relative costs for a given length are as 1: 0.90, or in other words, length for length, at a cost of

10 per cent. less than cast iron pipes. With regard to carriage, the rate per ton by rail is the same for either cast iron or mild steel pipes, and as the saving is in the direct ratio of dead weight for a given length, the cost of railway carriage is 78 per cent. less than on cast iron pipes, and a like saving can be effected in handling the pipes at the site of the track in which they are to be laid.

"The next point to which attention is directed is the jointing. As mild steel pipes are so much lighter than cast iron pipes, it is clear that they may be conveniently handled in longer lengths. The system of construction also favours this, and in fact the pipes may be made in one continuous length, built upon the site if it is desired. The customary methods are to make them in lengths of 24 feet, this being twice the usual length of cast iron pipe, and there are, consequently, only half the number of joints. Taking the 24 inch pipes before mentioned, the lengths and weights would be

	Cast Iron.	*Mild Steel.*
Diameter	24 inches	24 inches
Length of each pipe	12 feet	24 feet
Weight do	24.8 cwt.	10.47 cwt.
Relative weights per pipe	1	0.42
" lengths "	1	2

"Again, taking the case of one mile in length, 440 pipes would be required in cast iron, and only 220 in mild steel, consequently, there is a saving of 50 per cent. in the labour and cost of jointing a given length. Then with regard to each joint, the mean circumference of the space for lead in an ordinary cast iron socket joint is greater than in a mild steel pipe, in consequence of the greater thickness of cast iron. The reduction in the circumference of a mild steel socket is equal to a saving of 9½ per cent. upon the weight of lead required for a 24 inch cast iron pipe socket; assuming that the depth of lead is the same in each case, the total saving in lead is therefore 59½ per cent.

"To shew the final economical result in the case of one mile of 24 inch pipes previously mentioned, the several relative costs are:

	Cast Iron.	*Mild Steel.*	*Saving.*
Internal diameter, inches	24	24	
Length, mile	1	1	
Number of pipes	440	220	
Weight of each pipe, cwts.	24.8	10.47	
" one mile, tons	545.6	115.2	
Relative cost per ton	1	4.25	
" of carriage, per ton	1	1	

	Cast Iron.	*Mild Steel.*	*Saving.*
Relative cost of Carriage on total....	1	0.2111	78 p.c.
" of laying per yard.....	1	0.7	30 p.c.
Relative number of joints.....	1	0.5	50 p.c.
" weight of lead, each joint....	1	0.905	9½ p.c.
" " " each mile	1	0.405	59½ p.c.
" cost of making each joint ...	1	0.8	20 p.c.
" " jointing one mile.....	1	0.40	60 p.c.
" cost of total for one mile....	1	0.9	10 p.c.
" " of pipes and carriage...	1	0.84	16 p.c.
" " of carriage and laying.	1	0.834	16.6 p.c.
" " of pipes, carriage, laying and jointing one mile.....	1	0.788	21.2 p.c.

"The saving actually effected in the total outlay for one mile of 24 inch pipes, is therefore:

Cost of pipes.	*Cost of carriage.*	*Cost of laying.*	*Cost of jointing.*
10 p.c.	6 p.c.	0.6 p.c.	4.6 p.c.

or a grand total of 21.2 p.c."

It will be seen that the above extracts treat of a comparison between cast iron mains, and mild steel mains fitted with faucets and spigots. This is a cumbersome arrangement, and has been entirely discarded on the Pacific coast, the Moore and Smith joint, a description of which will be given further on, taking its place. This joint is specially adapted to all pipes between the diameter of 12″ and 24″. When of larger sizes the pipes are made in plain lengths of 24 feet 6 inches, and riveted together in the trench.

THE MAINS.

The rivetted mild steel mains in use by the Vancouver Water Works Company are of three diameters, 22 inches, 16 inches, and 12 inches. The 22 inch is laid from the dam to the tunnel, a distance of 13,530 feet, the 16 inch from the tunnel to ordinary high water mark of Burrard Inlet on the north shore, and from ordinary high water mark on the south shore to the centre of the city, a total distance of 39,211 feet. The 12 inch are laid on both shores of Burrard Inlet, between ordinary high water marks, and the submerged 12 inch flexible main across the Inlet, a total distance of 747 feet.

The 22 inch and 16 inch pipes are $\frac{11}{100}$ in. in thickness, and the 12 inch $\frac{8}{16}$ in. The latter, being laid below high water mark, require greater thickness of metal to withstand the corrosive influence

of salt water. These pipes were manufactured from plates imported from England by the Company, and rolled, rivetted, coated with asphaltum, and laid in trench by the Albion Iron Works Company of Victoria, B.C. Plate XX shews a longitudinal section of the 16 inch pipe. The 22 inch and 12 inch pipes are constructed in an exactly similar manner. It will be seen that the pipe is made in 7 courses, 4 large or outside courses, and 3 smaller or inside courses, rivetted together, and having a projecting nipple at one end. At the foundry, the plates were trimmed to the exact sizes required, and the rivet holes punched with multiple punches at one and the same time. Absolute uniformity in size and spacing of rivet holes was thus secured. Each plate was then rolled in the usual manner, by means of three parallel revolving cylinders, which gave it the circular form of the required diameter. It was then made to encircle the vertical cylinder of a hydraulic rivetting machine, which cold rivetted the straight or longitudinal seams. When 7 plates had been treated in this manner and converted into cylinders 3 ft. 6 in. long, and of diameters differing sufficiently to allow the ends of the smaller cylinders to be passed into the ends of the larger, they were rivetted together, so as to form one length. On the lap, between two thicknesses of steel at the end of each course, the plate was scraped down to a fine edge, and a rivet driven through. Where three thicknesses of metal came together, as when the longitudinal seams of the large course overlap the smaller course, extra heavy lap rivets were used. The edges of each sheet for 3 inches from the laps were chipped and caulked. Straight and round seams were split caulked. The whole length was then heated in an oven, and immersed in a bath of hot asphaltum. This bath was an iron trough, 26 feet long and 3 feet wide, supported on brickwork, and so arranged that a fire could be kept constantly burning underneath. In preparing the mixture, the trough was filled to within a few inches of the top with asphaltum broken up into small cubes of about an inch to the side.

Coal tar, devoid of all oily matter, was then poured in till the asphaltum cubes were completely covered. The mixture was then allowed to boil for three hours, being constantly stirred during the process. As many pipes as the mixture would cover were then dipped and allowed to dry. The coating obtained was smooth, tough, free from brittleness, and of uniform thickness.

The form of joint used in connecting these pipes is, as before stated, that invented by Joseph Moore and Francis Smith, employees of the Risdon Iron Works Co., San Francisco. Plate XX shews a longitudinal section of this joint. In making the joint in the trenches, the

nipple end of one length of pipe was forced into the larger end of the adjoining length, by means of hammering on wooden blocks placed against the end opposite the nipple. The abutting ends of the two lengths were not driven up tight, a space of from $\frac{1}{4}$ to $\frac{1}{2}$ an inch being left, for the purpose of allowing for any expansion or contraction that might take place. The outside surface of the pipes was then scarped clean for about $2\frac{1}{2}$ inches back from the junction of the two ends. A band or ring of diameter sufficiently great to allow of $\frac{1}{16}$ inch play between its inside surface and the outside surface of the pipe, was then made to encircle the junction. The space between was filled up with lead in the usual manner, and carefully caulked. Joints made after this pattern, have been in use for 15 years, and have given entire satisfaction. Care must be taken in making this joint, that no angle greater than one degree is made at the junction of the two lengths of pipe, otherwise the lead packing will be of unequal thickness, and will, in all probability, result in a leaky joint. Caulkers, accustomed to jointing cast iron pipes, must be cautioned, when making for the first time, a Moore and Smith joint, that the steel pipe will only admit of the lead being packed to a certain firmness, the degree of which can only be ascertained by actual trial. If the lead is beaten in between the ring and the pipe too tightly, the shell of the latter will bend inward, and render good work impossible.

As before stated, steel mains of more than 24 inches diameter, when subject to heavy pressure, are usually made in specified lengths at the foundry, and rivetted together in the trench. To accomplish this, it is necessary that each length shall have a large course at one end, and a small one at the other. The large course has its extreme end punched for rivets at the foundry, while the small course at the other end of the length is unpunched.

The pipes being placed in the trench, the small course of one length is forced by hammering, or other power, into the punched large course of the adjoining length. The position of the rivet holes on the small course, to correspond with those on the large course, are then marked and screw punched after separation. This being done, the two lengths are again united, their surfaces pressed firmly against each other by means of a set stool, and cold rivetted from the outside. The seam is split caulked in the usual manner. This makes the most desirable connection for pipes of large diameter.

However, it may be mentioned, that a pipe of 41 inches diameter, and subject to a pressure of 300 feet, was laid, ten years ago, in the Sandwich Islands. The lengths were connected by Moore & Smith joints, and are in active service to this day.

The Vancouver pipes were laid in the trench with the straight seams upwards, so that any leakage might readily be detected, and repaired by further split caulking. In most systems, however, the straight seams are laid downwards, the advantage of which is that in course of time, sediment gathers on the bottom of the pipe along the edges of the seams, and tends to prevent leakage. (See Appendix, p. 361.)

BENDS AND CASTINGS.

Inasmuch as the steel mains described in the foregoing pages were constructed with a view to securing absolutely tight joints, the outside surfaces of the nipples fitted tightly against the inside surfaces of the adjoining lengths. Consequently, no deviation from a straight line greater than one degree, could be made between any two lengths with out special bends. By means of specially adapted machinery, steel elbows and bends are made by certain manufacturers, but these lack stability when the angle of curvature is large. All bends in the Vancouver system are of cast iron, one inch thick. They are segments of a circle, the axis of the bend being the circumference, and the radius five feet. Previous to leaving the foundry, they were individually subjected to a pressure of 300 lbs. per square inch.

In certain parts of the pipe line, north of Burrard Inlet, the ground traversed, being contiguous to the river, is irregular horizontally and vertically, and required bends ranging from 5 to 70 degrees angle of deflection. That portion of the pipe line immediately south of the tunnel, and following the irregularities of the side hill for a distance of 8000 feet, required no less than 80 bends of all angles of deflection, being an average of one bend to every 100 feet of length. The total number required by the system from the point of supply to the centre of the city were 179. (See Appendix, p. 363.)

The other castings connected with the mains, not including the connections with the city distribution system, are as follows: two miles and a half below the dam, at the lowest depression between the dam and the tunnel is placed a blow off, 8″ off 22″. This is controlled by an eight inch valve, leading into a 12″ × 12″ box drain, which in turn leads to the river. To the middle pipe length in the tunnel is affixed a self-acting Chabot air valve, the air passage of which is $2\frac{1}{4}$ inches diameter, and is controlled by a brass valve, so that the upper part containing the rubber ball may be taken off for examination at any time without the necessity of shutting off the main at the dam.

At Burrard Inlet, on the north side is placed a blow off, 8″ off 16″ and on the south side, 12″ off 16″, reducing to 8″, both controlled by valves, and emptying into Burrard Inlet. The ends of the 16 inch main, on both sides of the inlet, are provided with "Y" breeches, two 12 inch branches off 16 inch. These branches connect with the double line of 12 inch mains, that will ultimately cross Burrard Inlet, and are individually controlled by 12 inch valves, so that each main can be shut off independently if required. Between the Inlet and Coal Harbour, on the highest elevation between the two waters, is placed another Chabot air valve, arranged in a manner similar to the one already described.

On both sides of Coal Harbour are placed blow offs, 8″ off 16″ discharging into Coal Harbour, and finally a 16 inch valve is located at the point where the mains enter the inhabited part of the city. It will thus be seen that in case of necessity the supply to the city can be shut off at five different places, viz., at the entrance and outlet of well chambers at the dam, on both sides of Burrard Inlet, and at the entrance to the city.

DISTRIBUTION OF MAINS, LEAD AND CASTINGS.

Inasmuch as the pipe line between the centre of the City and Coal Harbour follows well graded streets, the distribution of steel mains, lead and castings was attended with little or no difficulty. Ordinary four-wheeled drays, drawn by two horses and accompanied by two teamsters, accomplished this work in a most satisfactory manner, at a cost of $3.00 per ton.

The flexible mains for the crossings of Coal Harbour and Burrard Inlet, were transported on scows and discharged on the beach between high and low water mark at a cost of $5.00 per ton.

Between Coal Harbour and Burrard Inlet the first difficulties were encountered. The land between these two waters being heavily timbered, and only accessible by waggon road at both ends, rendered necessary the construction of a temporary road parallel to the pipe trench, and within easy reach of it. This was of the simplest character, being a roughly graded track, 8 feet wide, along which and at right angles to it were placed, at regular intervals of ten feet, rough undressed skids. Sleighs similar to those used by loggers in winter, and drawn by two powerful horses, carried two lengths of pipe per load along this road and deposited them where required. The cost of this service, including the construction of road, averaged $5.00 per ton.

Between Burrard Inlet and the Dam the work of distribution was accomplished under very great difficulties. As before stated, the country traversed by the pipe line is very irregular and heavily timbered. No roads exist in the vicinity, and the construction of an economical mode of conveyance for the 480 tons of steel mains, lead and castings, which were to be laid continuously along the pipe trench, was a problem, the solution of which involved considerable ingenuity. The mode adopted was a combination of waggon road and tramway. A tramway 15,400 feet long was built from the Inlet to a point on the side hill ground, about 4,000 feet south of the rock tunnel. This tramway is of three feet gauge with 4″ and 5″ track timbers, supported on ties placed four feet apart. At four points in its course there occur sudden breaks in ground level. The first takes place 5,800 feet north of the Inlet, the ground rising 37 feet in a distance of 135 feet; the second at 9,400 feet north of the Inlet, the ground rising 54 feet in a distance of 260 feet; the third at 11,100 feet north of the Inlet, the ground rising 27 feet in a distance of 82; and the fourth at the termination of the tramway, where it leaves the pipe trench and climbs the face of the side hill to the flat above. The total rise at this point is 80 feet in a distance of 150 feet. In distributing the pipes along the tramway, each car, pulled by one horse, carried three lengths of 16-inch pipe. On arrival at one of the above-mentioned changes of level, the horse was removed from the car to the top of the rise, where it was made to haul on a cable connected with the car, until the car also had reached the top. At the termination of the tramway a waggon road was built following the edge of the flat, a distance of 4,000 feet, to the rock tunnel. At suitable intervals clearings were made from the waggon road to the pipe trench on the side hill below, down which the pipe lengths were lowered, one at a time, by cables.

At the rock tunnel the face of the Cañon slopes downwards 164 feet in a distance of 400 feet. A short tramway was built down this steep descent, and loaded cars lowered down by cables. From the foot of this Cañon a waggon road was built and operated in a manner similar to that between Coal Harbour and Burrard Inlet.

The prices paid for the distribution of mains, lead and castings north of Burrard Inlet were, for the first 1268 feet $7.64 per ton, for the next 18,859 feet $12.87 per ton, and for the next 13,516 feet $14.85 per ton. These prices included the building of the tramway and the waggon roads as well as the cost of the distributing mains.

LAYING THE SUBMERGED MAIN AT FIRST NARROWS.

Having in view the difficulty of effecting repairs in pipes laid under water, and the disastrous consequences that might result from a temporary stoppage of the city's water supply should a break take place, through unavoidable causes, the design for crossing the first narrows, instead of being one 16 inch main, comprised its equivalent, two separate lines of 12 inch mains, 50 feet apart, and capable of independent action by means of stop valves placed at high water mark on each side of the Inlet. Up to the present only one of these lines has been laid in position on the bed of the Inlet, made up of 746 feet of plain rivetted steel pipes; 261 feet of rivetted steel pipe, fitted with cast iron flexible joints, and 1236 feet of cast iron flexible joint pipe.

The plain rivetted steel pipe is placed at each end of the line, 584 feet on the north shore and 162 feet on the south shore. The rivetted steel pipe with flexible joints is placed on the north shore between the plain pipes and the cast iron flexible pipes, and the latter are placed on the bed of the Inlet, reaching from low water to low water mark.

The construction and details of the plain pipe have been already described. The flexible steel pipe is in lengths of 22′ 2″ over all, and is exactly similar to the plain pipe, but provided with cast iron spigots and faucets, bored and turned in the same manner as the cast iron flexible pipes. The latter are of the pattern known as the Ward patent flexible joint pipe. They were manufactured in Scotland, and are of hard close grained white cast iron, thoroughly coated with Dr. Smith's coal pitch varnish. Each length is 12′ 4″ over all, $\frac{11}{16}$in. thick, weighs 1280 lbs., and is warranted by the manufacturers to stand with safety the pressure due to a column of water 600 feet high. Each joint required 70 lbs. of the best Spanish pig lead. Plate XX shews a longitudinal section of this joint. The larger portion of the inside surface of the bell or faucet forms a spherical zone, the centre of which is a point on the axis of the faucets at such a distance from its mouth, that the inside diameter of the latter is greater by half an inch than the inside diameter of the shoulder. The extreme end of the spigot is turned truly, and exactly fits the inside surface of the faucet. The outer end, or the end encircled by the mouth of the faucet, is of smaller diameter, so as to allow half an inch of space between the two surfaces

for lead packing. At the middle of the spigot is a circular groove, a quarter of an inch deep and an inch and a half wide, which serves the purpose of retaining the lead packing, and prevents the joint from pulling asunder, when exposed to tensile strain. This joint is capable of motion through an angle of 12 degrees, and a complete circle can be made with 30 lengths.

The contract for furnishing and laying the single line of cast iron flexible joint pipe was let on the 1st of November, 1887, to the inventor and patentee of the joint, Mr. John F. Ward, late chief engineer of the Jersey City Water Works. The price agreed on, which covered all risks and contingencies, was nine dollars per lineal foot.

Mr. Ward has devoted many years of his life to laying submerged pipes of all diameters, and has, hitherto, met with unfailing success. Among some of the more prominent works standing to his credit, may be mentioned the six inch pipe crossing the Delaware River at Easton, Pa., the 12 inch pipe, 963 feet long above the dam, at Lawrence, Mass., and the two lines of 8 inch pipe crossing Shirley Gut, Boston Harbour, a channel 400 feet wide, and 37 feet deep, through which a tidal current flows at the rate of 7½ miles per hour.

Mr. Ward, on his arrival, made a thorough inspection of the crossing, and expressed himself as confident of being able to complete his contract with ease and rapidity. Accordingly on the 21st of April, 1888, he began operations, his plan being to joint the pipes on a suitable platform stationed at low water mark on the north shore, and by means of a stationary engine on the south shore, to haul them across, length by length. Inasmuch as Mr. Ward failed to carry out this plan to completion, the writer, without expressing any opinion as to its practicability, will merely describe his mode of procedure.

The structure erected on the north shore of the Inlet, on which the pipes were jointed, was a frame work staging of sufficient height to reach above extreme high water, and strong enough to resist the force of the incoming and outgoing tides. In the middle of this stage was constructed a sloping platform, extending from the front face, 4 feet below the top, down to the ground at the rear face, or the face fronting the Inlet. The object of the platform was to admit of the pipes being jointed in an inclined position, and therefore sliding easily to the ground, when the hauling power was applied. The 104 lengths of pipe required to reach from shore to shore were piled within easy reach of the platform. The engine on the south side of the river, opposite the platform and at a distance of 1400 feet from it, was of 30 H. P., and revolved an ordinary drum, to which was attached a hundred feet of wrought

iron chain, connecting with a continuous wrought iron rod of 1¼ inches diameter. This rod reached clear across the Inlet, and was attached to the rear end of the first length of pipe lying on the sloping platform of the staging. The rod was made from round iron in lengths of 51 feet, jointed together by common screw unions, its whole tensile strength being that due to the resistance offered to stripping by the threads of the unions.

When Mr. Ward had completed these arrangements, he began without delay to joint the lengths together. To the length lying on the platform, the spigot end of which faced the Inlet, a second length was jointed in the usual manner.

The engine on the south side was then put in motion, and the first length hauled forward a distance equal to its own length, leaving the second length to fill the place previously occupied by the first. A third length was then jointed to the second, the engine again pulled forward, until the third length occupied the place vacated by the second. It was intended to repeat this operation until the whole 104 lengths had been dragged across the bottom of the Inlet. However, after 18 lengths, covering a distance of 216 feet, had been submerged, Mr. Ward concluded to substitute a steel wire cable for the wrought iron rod. In stretching this cable across the Inlet, it unfortunately fouled on a small boulder, about 200 feet above the pipe line, and such efforts as were made to dislodge it proved unavailing. Mr. Ward then notified the company that urgent private business compelled him to leave the works for St. Paul, Minn. He did not return, but shortly afterwards officially abandoned the contract.

On July 9th, more than a month after Mr. Ward's failure, the company contracted with Messrs. H. F. Keefer and D. McGillivray, the gentlemen who already held the contract for trenching and refilling, to complete the work according to certain specifications, from which the following clauses are extracted:

"The total length of the crossing to be made is 1248 feet, extending from low water mark on the south shore to low water mark on the north shore. These points will be defined by stakes placed by the company's engineer, and the whole main when finally laid shall be in a perfectly straight line between them.

"Each pipe length, previous to being placed in position, shall be well and carefully tested for flaws in manufacture, cracks, air-holes, and other defects, by the usual process of suspending in slings and tapping with hammer. Should any be found defective, they shall be discarded, and the engineer notified of the same.

"The lead to be used in jointing shall be that known as 'Best Spanish Pig.'

"The whole number of pipe lengths, previous to being placed in final position on the bed of the first narrows, shall be jointed, leaded, and made perfectly water-tight on dry land, and on such a structure as will admit of the whole length of 1248 feet being of easy access for the purpose of inspection.

"A test pressure of not less than 300 lbs. per square inch shall then be applied by the contractors, in the presence of the Company's Engineer, the leakage under which, throughout the whole length of 1248 feet, shall not exceed one cubic foot per minute. Such joints as may prove defective under this pressure shall be made good by the contractors at their own expense, and such pipe lengths as may leak or give evidence of flaws shall be removed by the contractors, and replaced by sound lengths, the cost of which shall be defrayed by the company.

"The Engineer's approval of the main, after the application of the above test being given, the contractors shall be at liberty to place it in position on the bed of the first narrows, which being done, a similar test pressure of 300 lbs. per square inch, subject to the same conditions, shall be applied.

"A diver will be appointed by the company to inspect the main when finally laid in position, and on his report such alterations in its position as may be rendered necessary by reason of its resting on boulders or sharp irregularities of the bed of the Inlet, shall be made by the contractors, and at their expense, provided the total cost does not exceed five hundred dollars. All costs over this amount shall be defrayed by the company."

Messrs. Keefer and McGillivray entered into the fulfilment of their contract with energy. A 30 H. P. engine was stationed on the north shore of the Inlet, between high and low water marks. With this the 18 lengths submerged by Mr. Ward were hauled back to dry land. A trench, 4 feet wide, 4 feet deep, and 1300 feet long, was excavated on the line of the crossing on the north shore. Parallel continuous runners of barked fir, three in number, were placed in the bottom of the trench, in such a manner that the bell end of each pipe when jointed would rest on the central runner, and be supported on each side by the other two runners. A frame work staging, similar to that employed by Mr. Ward, was built over the trench and supported on rollers, on which it could readily be moved over the whole length of the trench. On this staging with its sloping platform, the whole number of pipe lengths were jointed, the operation being very similar to that of

paying off a cable from a moving ship. As soon as the first joint was made, the staging was moved forward till the first pipe length rested on the runners in the trench, leaving the second in the place vacated by the first. A third pipe was then hoisted up by winches, its spigot end inserted into the bell of the second, and carefully adjusted in exact line. Molten lead was then poured in and caulked in the usual manner. This done, the staging was again moved forward and another pipe adjusted, the operation being repeated day by day, till one hundred lengths had been connected. As before stated 104 lengths were provided, but during the process of jointing, four, shewing evident signs of fracture, were discarded.

Immediately on the completion of the work of jointing, both ends of the chain of pipes were securely capped, and the stipulated test pressure of 300 lbs. per square inch applied.

A first attempt was made to apply the pressure by means of a hand pump, worked by six men, forcing a stream of water into a circular opening, one inch in diameter, provided for that purpose in the cap on the north end. It was speedily found, however, that owing to the leakage at the joints, slight as it was, this method was not powerful enough to keep the chain of pipes full and attain the required pressure. The stationary engine, situated midway between high and low water mark, was then brought into requisition. The middle length of the chain of pipes was tapped, and by means of the engine, water was pumped in until the first defective pipe manifested itself, which occurred when the gauge registered 30 lbs. per square inch. This length was immediately broken up by sledge hammers, the bell cut by a cold chisel, split open, and the lead removed.

The two portions of the chain of pipes were then hauled together by means of the engine, and re-jointed. Pressure was again applied until the second injured pipe gave way.

This operation was repeated until no less than eight defective pipes had been removed. The remaining 92 sustained the required pressure of 300 lbs. per square inch for a period of five minutes, during which each length was subjected to heavy blows from a 12 lb. hammer. As the joints sustained this severe pressure without exceeding the specified amount of leakage, and as every length seemed to be absolutely free from defects, the test was considered eminently satisfactory. The following table shews the pressures at which the different pipe lengths gave evidence of the fractures they had sustained during their repeated handlings, and which were not detected by the process of "ringing."

Number of Length, reckoning from north end of pipe chain.	Pressure per square inch under which pipe gave way.	Nature of fracture.
5th	30	Longitudinal crack 12″ long
9th	70	" " 36″ "
10th	60	" " 36″ "
31st	50	" " 12″ "
37th	70	" " 18″ "
38th	70	" " 18″ "
51st	40	" " 24″ "
64th	40	" " 12″ "

Notwithstanding the additional loss of these 8 pipes, it was deemed advisable to proceed with the submersion of the remaining 92, the shelving nature of the north shore being such that the north end of the chain of pipes, when laid in position, would not be covered by more than two feet of water at low tide, and, therefore, it would be no difficult matter to raise that end at any future convenient time, and add the whole 12 lengths necessary to complete the crossing as planned.

The plan adopted for placing this long line of heavy flexible pipes in position on the bed of the Inlet was direct hauling from shore to shore, during the half tides which occur in the Inlet during the months of July and August. For the purpose of lessening the weight as much as possible, each length was encircled by a wrought iron ring, to each of which floats of 500 lbs. buoyancy were attached. To prevent as much as possible the forward end of the chain of pipes from ploughing a deep furrow in the bed of the Inlet during the process of hauling, it was buoyed up by a number of cedar logs laid lengthways. The hauling gear was as follows—(See Plate XIX). To the rear end, that is the end farthest from the water, was attached a 9 inch manilla cable of 44,800 lbs. ultimate tensile strength, and 600 feet long, which was connected with the 30 H. P. Engine, stationed on the same shore, midway between high and low water marks. To the middle length was attached a 4 inch steel cable of 52,000 lbs. ultimate strength, and 1880 feet long, which connected with a 30 H. P. engine stationed on the south or opposite shore. Midway between the middle length and the forward end of the chain of pipes, a similar steel cable 1,600 feet long was attached, which also connected with a 30 H. P. engine on the opposite shore. A third steel cable of the same strength, and 1,325 feet long, was attached to the forward end of the chain of pipes. This latter connected with two 30 H. P. engines on the opposite shore. It will thus be seen that there were no less than three 4 inch steel wire

cables, and one 9 inch manilla cable attached to the chain of pipes, the total ultimate strength of which was very nearly 90 tons. The total effective strength of the engines pulling the tackle connected with these cables aggregated 150 horse power.

The four engines on the south side were stationed on the beach at high water mark. The blocks and tackle were arranged in three parallel rows 10 feet apart on the flat immediately to the rear of the engines. This flat being densely timbered with the huge trees peculiar to the Pacific coast, the space cleared in which to operate the tackle was necessarily limited. The blocks were securely anchored to huge stumps in the vicinity by heavy wrought iron chains. The pulleys, one of which was four sheaved and two three sheaved, had a clear distance of 56 feet in which to operate. The manilla cables passing through the sheaves were connected to the wire cables by wrought iron grips invented for the occasion by the contractors.

All arrangements having been satisfactorily completed, the engines were set in motion on the 28th of August, 1888, at 10 a. m. The steel cables straightened out and remained taut and stationary, but only for a minute. A sudden slackening took place, and the whole chain of pipes took a forward motion of several feet, and from that instant the success of the undertaking was an assured fact. There had been a question as to whether the joints would withstand the enormous tensile strain brought to bear on them, but it now became certain that the lead packing would remain intact as long as the cast iron bell held together.

Owing to the extreme distance between the blocks and pulleys being no more than 56 feet, the tackle connecting them had to be overhauled every advance of 56 feet made by the chain of pipes. The process of hauling was therefore necessarily slow; but being kept up without intermission, at 7 p. m. the forward end of the chain of pipes arrived at its destination on the south shore.

On the day following, at slack tide, a skillful marine diver walked across the bed of the Inlet, following the chain of pipes, entering on the south shore and emerging on the north. His report was to the effect that the whole line of pipes was lying on the bed of the Inlet in a perfectly straight line, without sag or bend, that the heavy projecting bells of the pipes, as they were being drawn over, had scooped a deep groove in the soft sandstone rock, and that the whole chain of pipes was resting in a rock trench of its own excavating; that above this trench silt was rapidly gathering, and that in his unqualified opinion the pipes would

in a few weeks be entirely covered over, rendering their permanency and safety beyond question.

The day following this examination, the contractors applied the final test pressure of 300 lbs. per square inch as called for by the specifications. An opening was made in the cap on the end length, the pipes filled with water by steam pumps, and the required pressure steadily maintained for five minutes of time, without perceptible leakage. The enormous strain on the joints apparently had no other than a beneficial effect, having compacted the lead, and rendered the whole line perfectly water-tight. Eleven of the 12 pipes which had been discarded were subsequently replaced by pipes cast by the Albion Iron Works Co. of Victoria, tested to a pressure of 300 lbs. per square inch before leaving the foundry. No difficulty was experienced in attaching these to the main already submerged. The end of that main having been lifted up was buoyed on the deck of a small scow. The additional lengths were added one by one, the scow being moved forward as each length was jointed, until the whole eleven rested in position on the bed of the Inlet. It was found, however, at a later date that owing to the shelving nature of the north shore, and the fluctuations of the tides, a satisfactory connection between the end of the cast iron flexible pipe and the plain rivetted steel pipes could not be made. Twelve of the latter were accordingly fitted with flexible cast iron spigots and faucets, similar to those shewn on Plate XX, and connected with the cast iron pipes, making a total length of 1496½ feet of flexible pipe, covering a horizontal distance of 1483½ feet.

When the project for supplying the city of Vancouver with water from the River Capilano, by means of a submerged main across Burrard Inlet, was first made public, considerable interest was evinced by both engineers and civilians. Printers' ink was called into requisition and many articles published demonstrating the utter impracticability of the project.

The complete success of the undertaking is an irrefutable answer to all the adverse theories advanced. However, it may be of interest, even at this late day, to mention some of the objections urged and believed in up to the successful completion of the work, and the published answers thereto.

Objection 1.

That the known force of the current in the first narrows would cause the chain of pipes to sway up and down the bed of the Inlet with each change of tide, and eventually result in separation of the joints.

Answer—That it could be mathematically demonstrated (calculation

shewn), that the force of the current was altogether insufficient to produce the results stated, and that the proposed method of laying the pipes by "direct hauling" from shore to shore would result in the sharp-edged bells of the pipes cutting a groove, sufficiently deep to embed the whole chain, and thus effectually destroy the possibility of motion.

Objection 2.

That the current would create a friction that would scour off any coating that might be put on to protect the pipes from corrosion.

Answer.—That the pipes being embedded in the bottom of the inlet, and covered by silt, would be absolutely free from frictional action.

Objection 3.

That vessels might accidentally drop anchor on the pipes, or that vessels, finding themselves in danger of drifting ashore, through stress of weather or other causes, might be obliged to drop their anchors on the bottom, and as a result hook on to the chain of pipes and break it asunder.

Answer.—That the thickness of the pipe shells if exposed to the shock of a falling anchor would be sufficient to keep them intact, and that if the anchor fluke of a drifting vessel were to bury itself under the chain of pipes, the vessel would be securely anchored, and would be obliged to wait for the turn of the tide to free herself, such cases occurring daily in Boston Harbour and elsewhere.

Objection 4.

That salt water would cause galvanic action of a destructive nature to take place at the joints where lead and cast iron were in close contact.

Answer.—That there is no instance on record of destructive galvanic action having occurred in the case of lead and cast iron in contact under salt water.

Objection 5.

That the chain of pipes, being of cast iron, would, owing to the action of salt water, speedily become soft like plumbago, and in a few months become utterly worthless.

Answer.—That softening of cast iron exposed to the action of salt water takes place only in castings of inferior metal, and that it is on record that castings of close grained, hard, white metal had resisted the corroding action of salt water for 40 years and upwards.

Objection 6.

That in the case of a Narrows, connecting a large inland basin with the sea, where the tide has a rise and fall of 12 feet, the counter cur-

rents in such a restricted passage defied calculation, and were more likely to be greater at the bottom than at the surface.

Answer.—That the laws of nature are unchangeable, and that the future experiments of the company's engineers would amply demonstrate that it was impossible for a current exposed to the influence of a vast friction bed, like the bottom of Burrard Inlet, to be greater than the free and unrestricted current of the surface.

Objection 7.

That the great force of the current rendered it imperative that the whole chain of pipes should be laid in the short interval of slack water between two tides, which did not exceed twenty minutes duration, and that no means could be devised to perform such an arduous undertaking in such a short period of time.

Answer.—That the method proposed by the company, of jointing the pipes and hauling them in a continuous chain across the inlet, would, as before stated, entrench the pipes, and cause a resistance to motion which would render it immaterial whether the pipes were laid in twenty minutes or twenty hours.

Objection 8.

That the method of laying the pipes proposed by the company, viz.—jointing and hauling in one continuous chain, was impossible, as no pipe joint could be made strong enough to withstand the enormous tensile strain this method would entail.

Answer—That the construction of the Ward flexible joint was of such a nature that the lead packing could not be pulled out, and before a joint could break asunder, it would be necessary for the cast iron bell to give way, and that in consequence the strength of the joint was limited only by the sectional area of cast iron exposed to the tensile strain.

Objection 9.

That there were no instances on record of pipes laid in salt water subject to a tidal current of 9 miles per hour, where the depth of the channel was 60 feet, and the width 1240 feet.

Answer—That this was most certainly true, and that when the Vancouver Company's submerged main was laid, it would serve as a precedent for similar works on a more gigantic scale.

The above objections and answers, and many more of a like nature, were publicly discussed and argued upon by professional men. Elaborate and specious mathematical calculations were produced in support of each theory. However, as the work is now an accomplished fact, all opposing theories are thereby proved worthless.

In regard to the ninth objection, the writer is well aware that no similar work of a like magnitude has ever been attempted. Greater lengths of flexible pipes have been laid in lakes, rivers. and ocean bays; but previous to the laying of the submerged main across Burrard Inlet, no pipe of 12 inches diameter and 1100 feet in length had been laid in salt water 60 feet deep, on a smooth rock bottom, and exposed to a tidal current of 9 miles per hour. The nearest approach to it is the Shirley Gut pipe, 8 inches diameter, laid by Mr. Ward many years ago, which, as before stated, crosses an arm of the sea, 400 feet wide, 37 feet deep, and subject to a tidal current of 7½ miles per hour. The double line of 16 inch flexible pipe laid across San Francisco Bay for the San Francisco Water Works Co. is the longest chain of submerged pipes yet laid. The pipes are seamless wrought iron tubes, 5-16″ thick, fitted with cast iron faucets and spigots after the Ward pattern. The bay, where the pipes cross, is 6300 feet wide, and entirely free from currents. A thousand feet out from the Alameda shore it is 60 feet deep, but at two thousand feet it is only 15 feet, and this latter depth gradually decreases till the San Francisco shore is reached. The pipes were jointed on a large scow, fitted with a derrick and sloping platform, and paid out from the rear as each successive length was added. The whole time occupied in jointing and paying out the double line was 40 days.

The following table shews the more prominent instances of submerged pipes, known to the writer as being laid previous to the laying of the Burrard Inlet pipes.

Main.	Length.	Water Works Co.	Where laid.
Single 36 inches.	4000	Toronto Water Works.	Lake Ontario.
" 36 "	3044	Milwaukee "	Lake Michigan.
" 36 "	2000	Jersey City "	Hudson River.
" 36 "	960	Philadelphia "	Delaware River
" 12 "	963	Lawrence "	
Double 16 "	6300	San Francisco "	San Francisco Bay.
" 8 "	400	Deer Island "	Shirley Gut.
Single 8 "	3100	San Diego "	San Diego Bay.
" 6 "	800	Easton "	Delaware River.

LAYING SUBMERGED MAIN ACROSS COAL HARBOUR.

Coal Harbour, being shallow and its bed easy of access at all stages of the tide, is crossed by a 16 inch rivetted steel main, 3-16″ thick, fitted with cast iron flexible joints, and costing $3.50 per lineal foot at the foundry. Plate XX shews the form of joint used. Three

hundred lineal feet of flexible pipe were provided, but at the time it was necessary to effect the crossing, it was found that unusually high tides prevailed, and that this amount was insufficient. This difficulty was overcome by rivetting two plain lengths to two flexible lengths, the compound lengths, each 48 feet long, being placed at the ends of crossing, the whole covering, when jointed, a distance of 348 feet. The submerging of the pipes was effected without difficulty in the following simple manner:

The total number of lengths were jointed in one continuous straight line on the south shore, between high and low water marks, the forward end resting on and firmly secured to a small scow.

The whole line was buoyed on each side by cedar floats, capable of sustaining the entire weight. On the rising of the tide, the scow and the chain of pipes rose with it, and when well afloat, a dozen men stationed on the opposite shore hauled on a small rope attached to the scow, pulling it forward, till the line of pipes was directly above its destined position on the bed of the Bay. The floats were then cut off, and the pipes allowed to sink to the bottom. At low water the ends of the chain were exposed, and connection with the 16 inch mains on each shore was effected without difficulty. The whole operation occupied three days from start to finish.

THE DISTRIBUTION SYSTEM.

The general plan of the distribution system was designed by Mr. T. C. Keefer, C. E., C.M.G., Past President of the Canadian Society of Civil Engineers. Its excellence is therefore beyond question. Subjoined are a few of the more important details.

The city of Vancouver is laid out on the rectangular system, the streets being 99 and 66 feet wide, forming blocks 260 feet wide by 500 feet long. The 16 inch steel main is carried under the principal streets into the centre of the city. Branching from it, at suitable intervals, by means of special castings, the larger sub-mains, 8″ and 6″ diameter, form rectangles, from the sides of which the smaller sub-mains, 4″, 2½″ and 2″ diameter, branch out in any required direction. The system is liberally supplied with stop valves. Each pipe feeding direct from the main, and each small sub-main feeding from the larger sub-mains, can be closed independently, when required. In the case of breaks and necessary repairs, a single street or part of a street can be shut off without interfering with the supply to other parts of the city. Should it ever become necessary to shut off the whole system, a 16 inch valve is provided on the main for this purpose, outside the limits of the distri-

bution system. In all cases the valves have been placed at a distance of four feet from the initial point of the sub-main, or from the intersecting centre of the two sub-mains. The sub-mains are laid at a distance of 20 feet from and parallel to the street lines, so that the exact locality of the valves can be found without difficulty, even in winter when the ground may be covered with snow and ice. In most cities the practice followed has been to locate the valves uniformly on the lines of the street boundaries, the disadvantage of which is that a break in a sub-main may occur between the valve and the feeding pipe, in which case the valve is rendered useless.

To resist the severe water hammer, due to the great pressure in the system, the valves are made unusually heavy.

The bodies, caps, and nuts are of cast iron; the spindles, stuffing boxes, glands and followers are of composition metal.

The plugs are of cast iron with composition faces, and spindle bushings. The following table gives their dimensions, weight and cost in Victoria.

STOP VALVES.

	Diameter in inches.					
	2″	4″	6″	8″	12″	16″
Shoulder to shoulder of Bells.....	3¾″	5¼″	6″	6⅝″	8″	9⅞″
Diameter of Bell in inches.....	3⅛″	5⅜″	7⅛″	10″	14⅛″	18⅛″
Aver. weight in lbs.	34	115	190	298	650	1100
Cost at Victoria....	$12.00	$17.50	30.00	$44.00	$85.00	$150.00

The body of each valve is enclosed in a square brick chamber, built to such a height that the top of the valve chamber (a small, square cast iron box, weighing 111lbs., and protecting the nut of the spindle), when placed upon it, is flush with the street.

The system is provided with 75 double valves, two hose Matthew's fire hydrants, with 4 inch valve openings. This hydrant is in general use throughout the United States. The manufacturers claim, and the claim is conceded by all cities using them, the following advantages over all others.

There being two main valves, possible leakage is reduced to a minimum. The lower valve, working independently of the upper valve, the hydrant can be disconnected for repairs, without the necessity of excavation, and without shutting off the feeding sub-main.

The rod and automatic waste valve, attached to the upper induction valve, work in such a manner that the opening of the lower induction valve involves the closing of the waste valve, and vice-versa. Waste of water cannot therefore take place, and no water can remain in the stock of the hydrant, when the upper valve is closed.

The lower valve being capable of independent action, the temporary removal of the upper valve for repairs does not interfere with the utility of the hydrant.

As previously stated, the works of excavation and pipe laying main included south of Burrard Inlet were carried out by the company by day labour. The average depth of trench for the mains was 3′ 10,″ and for the sub-mains 3 feet. The cost, including tools, laying pipes, placing specials, erecting hydrants, refilling and tamping trenches, taking up and replacing crossings, and works of a like nature, did not exceed 17 cents per lineal foot.

LETTING THE WATER INTO THE MAINS.

On Wednesday, the 20th of March, 1889, the gate in the well chambers of the dam was partially raised, and water allowed to flow for the first time into the 22″ main. The 8″ blow off near the rock tunnel was kept open, and the water was not allowed for several days to fill up to the level of the tunnel, and flow into the 16″ main. On March 25th at 4 p. m., the gate in the well chambers was opened wide, and a full head of water turned on. At 6 p. m. the 22″ main was filled, and began flowing through the tunnel into the 16″ main. At 9.45 p. m. the water reached the closed 12″ valves, on the north shore of Burrard Inlet. At 10 p. m. the valve controlling the 12″ submerged main was opened three-quarters full. At 10 minutes past 10 the water reached the south shore. At 3 a. m. it had reached the termination of the 16″ main in the centre of the city, and at 4 a. m. it was discharging fully into False Creek, by means of an 8 inch sub-main opened wide.

It is worthy of note that in the whole length of the mains, not a single joint was found to leak. Such leaks as were discovered occurred at the seams, where the rivetting and split caulking had been imperfectly done. These were speedily repaired by encircling the mains by steel rings, 4 inches wide, made in two halves, and provided with "Lugs."

The lugs were bolted together, above and below the main, the space between the ring and the pipe being filled up with lead, and carefully caulked in the usual manner.

From the drawings accompanying this paper, Plates XVI to XX have been prepared.

FINAL ESTIMATE COVERING ALL WORKS BETWEEN THE SUBMERGED MAIN, BURRARD INLET, AND THE CAPILANO DAM, BASED ON FINAL LOCATION OF PIPE LINE, MAY, JUNE, 1888.

Station. From	Station. To	Description of Work.	Quantities.	Rate.	Amount.
		TUNNELLING.		$	$
		6′ x 4′ in solid rock	Lin. ft. 280	15 00	4,200 00
		Earth filling on floor of tunnel	C. yds. 42	0 40	16 80
		Excavation of approaches to same in rock.....	" 283	2 50	707 50
		Excavation of approaches to same in earth.....	" 125	0 40	50 00
		6′ x 4′ in hardpan	Lin. ft. 108	6 50	702 00
		Excavation of approaches.	C. yds. $118\frac{4}{10}$	0 50	59 20
					5,735 50
		EXCAVATION AND REFILLING OF PIPE TRENCH.			
12+76	19+00	Hardpan and mud below high water mark.....	C. yds. 206	1 00	206 00
19+00	27+00	Earth and water below high water mark.....	" 322	0 75	241 50
27+00	48+00	Earth, small boulders and hardpan	" 1093	0 75	819 75
48+00	70+00	Earth and sand	" 1062	0 60	637 20
70+00	87+00	Gravel, hardpan and boulders	" 933	1 00	933 00
87+00	91+00	Earth and boulders	" 153	1 00	153 00
91+00	105+00	Earth, boulders and hardpan	" 753	1 00	753 00
105+00	122+00	Earth and boulders.....	" 879	1 00	879 00
122+00	128+00	Sand, clay and water....	" 333	1 00	333 00
128+00	131+50	Gravel and boulders.....	" 170	1 00	170 00
131+50	134+00	Earth and sand	" 152	0 60	91 20
134+00	144+00	Earth, hardpan and boulders	" 541	1 00	541 00
144+00	211+54	Earth, boulders and gravel	" 7,407	0 60	4,444 20
211+54	213+43	Solid rock	" 83	2 50	207 50
217+20	231+38	Earth and boulders.....	" 897	1 00	897 00
231+38	237+38	Sand and boulders.....	" 489	1 20	586 80
237+38	255+38	Earth, gravel and boulders.....	" 1162	1 20	1,394 40
255+38	268+38	Sand and boulders	" 735	1 00	735 00
268+38	270+28	Boulders	" 360	1 20	432 00
270+28	274+28	Earth, gravel and boulders.....	" 345	1 20	414 00
274+28	285+00	Earth, boulders and hardpan	" 698	1 20	837 60
285+00	293+00	Clay, gravel and boulders.	" 618	1 20	741 60
293+00	303+00	Earth, boulders and hardpan.....	" 611	1 20	733 20

Station. From	Station. To	Description of Work.	Quantities.	Rate.	Amount.
				$	$
303+00	308+50	Boulders.....	C. yds. 451	1 20	541 20
308+50	317+60	Sand, hardpan and boulders.....	" 611	1 20	733 20
317+60	320+00	Boulders	" 284	1 20	340 80
320+00	350+74	Earth, sand and boulders..	" 2,066	1 00	2,066 00
12+76	350+74	Excavation for 1,402 pipe joints.....	" 800	1 00	800 00
12+76	350+74	Additional excavation for pipe culverts under Streams	" 340	1 00	340 00
12+76	350+74	Catchwater drains at embankments	" 400	0 60	240 00
350+74		Filling pipe outlet at dam.	" 100	0 25	25 00
					22,267 15
		EMBANKMENTS.			
Earth		Over and under pipes at various points along pipe			
Gravel and boulder.		line	C. yds. 2,594	0 40	1,037 60
		At base of certain land slides.....	" 1,100	0 50	550 00
		Rip rap for same	" 900	0 50	450 00
					2,037 60
		CULVERTS.			
		Close fitted timber culverts, enclosing pipe above various embankments, and under various streams, including earth packing round pipes.....	L. ft. 860	2 50	2,150 00
		DISTRIBUTION OF PIPES, SLEEVES, LEAD, ETC.			
14+32	27+00	Hauling and distributing along line of trench, ready for laying, $36\frac{1}{8}$ lengths of 12" Steel rivetted mains $\frac{3}{16}$" thick, in lengths of 23', $9\frac{3}{4}$", each weighing, sleeve included, $715\frac{6}{10}$ lbs	Tons. $11\frac{61}{100}$	7 64	88 70
		Hauling and distributing as above castings and lead for 12" main.....	" 239	7 64	18 26

Station From	Station To	Description of Work.	Quantities.		Rate.	Amount.
22+34	27+00	Hauling and distributing as above 19 lengths of 16″ steel rivetted main, $\frac{11}{100}$″ thick, in lengths of 23′ 9¾″ each, weighing, sleeve included, 550$\frac{1}{1}$ lbs.....	Tons.	$4\frac{67}{100}$	$ 7 64	35 68
		Hauling and distributing lead for same.....	"	$0\frac{44}{100}$	7 64	3 37
26+00	215+59	Hauling and distributing as above 767 lengths of 16″ rivetted steel main $\frac{11}{100}$″ thick, in lengths of 23′, 9¾″, each weighing, sleeve included, 550$\frac{1}{10}$ lbs.....	"	$188\frac{86}{100}$	12 87$\frac{31}{47}$	2425 43
		Hauling and distributing as above, castings, lead and extra sleeves for 16″ main as above.....	"	$46\frac{16}{100}$	12 87$\frac{31}{47}$	594 38
27+00	215+59	Partially distributing 6 lengths of 16″ steel main (rivetted) as above....	"	$1\frac{48}{100}$	6 44	9 53
215+59	350+89	Hauling and distributing as above 568 lengths of 22″ steel rivetted main, $\frac{11}{100}$″ thick, in lengths of 23′ 9¾″ each weighing, sleeve included, 746$\frac{1}{10}$ lbs.....	"	$189\frac{87}{100}$	14 85	2812 14
		Hauling and distributing as above 2 rivetted steel thimbles for connection at dam, each weighing 242 lbs.....	"	$\frac{22}{100}$	14 85	3 27
		Hauling and distributiug as above, castings, lead and extra sleeves for 22″ mains.....	"	$30\frac{88}{100}$	14 85	458 57
		Partially distributing as above 7 lengths of 22″ rivetted steel main.....	"	$2\frac{34}{100}$	7 43	17 38
		Partially distributing as above 6′ 22″ castings...	"	$2\frac{33}{100}$	7 42	17 29
						$38,674 25

DETAILS OF RIVETTED STEEL MAINS.

DESCRIPTION.	12 inch Main.	16 inch Main.	22 inch Main.
Large plates	42 1/10" × 42"	53 1/10" × 42"	72 9/16" × 42"
Small plates	40 9/10" × 42"	53" × 42"	71 1/8" × 42"
Thickness of Plates	5/16"	11/100"	11/100"
Ultimate tensile strain per square inch	72000 lbs.	72000 lbs.	72000 lbs.
Weight of large plate	94.024 "	70.359 "	95.07 "
Weight of small plate	91.344 "	69.442 "	94.15 "
Number of large plates in one length	4	4	4
Number of small plates in one length	3	3	3
Total weight of plates in one length	650.128	489.762 lbs.	662.73 lbs.
Outside measurement of large plates in place	42"	42"	42"
Outside measurement of small plates in place	39 1/4"	39 1/4"	39 1/4"
Straight seam laps	2 1/8"	2 1/16"	2 1/16"
Round seam laps	1 1/8"	1 1/8"	1 1/8"
Length of pipe, exclusive of nipple	23'.93 3/4"	23' 9 3/4"	23'.93 3/4"
Nipple	38 5/10"×5"×11/100"	50 1/16"×5"×11/100"	69 3/4"×5"×11/100"
Exterior projection of nipple	3"	3"	3"
Weight of nipple	5.97 lbs.	7.94 lbs.	10.88 lbs.
Band	4" × 1/2"	4" × 1/4"	4" × 1/4"
Inside diameter of band	13 3/8"	17 6/100"	23 68/100"
Weight of band	24.72 lbs.	15.43 lbs.	20.77 lbs.
Outside diameter of pipe at joint.	12 1/4"	16.44"	22.42"
Thickness of lead in joint	5/16"	5/16"	5/16"
Weight of lead per joint	21.29 lbs.	27.30 lbs.	37.08 lbs.
Asphaltum coating 1/16" thick	20 1/2 "	27 "	37 "
Space between ends of pipes when laid	1/4"	1/4"	1/4"
Number of lengths per mile	221.538	221.538	221.538
Straight seam rivets, head	5/8" × 5/32"	5/8" × 1/32"	5/8" × 3/32"
Do do body	5/16"× 1"	5/16" × 5/8"	3/16 × 5/8"
Distance apart centre to centre	1.348"	1.4306"	1.4306"
Distance between each row	7/8"	11/16"	11/16"
Distance centre of row to edge of Plate	7/8"	11/16"	11/16"
Number of rivets in each row	28	28	28
Do per lb	40	51 9/10	51 9/10
Total number of seam rivets per length	392	392	392
Weight of seam rivets per length	9.8 lbs.	7.656 lbs.	7.656 lbs.
Round seam rivets, body	5/16" × 1"	5/16" × 5/8"	5/16" × 5/8"
Do do head	5/8" × 5/32"	5/8" × 5/32"	5/8" × 3/32"
Distance apart centre to centre	1178"	1.076"	1.068"
Distance centre of row to edge of plate	11/16"	11/16"	11/16"
Number of rivets per seam	34	48	66
Do per lb	40	51 9/10	51 9/10
Total number of round seam rivets	204	288	396
Weight of round seam rivets per length	5.1 lbs.	5.625 lbs.	7.734 lbs.

Weight of each length	690.928 lbs.	534.663 lbs.	726.078 lbs.
Weight per lineal foot	29.015 "	22.453 "	30.491 "
Steel Plates, less rivet holes, per mile	142,945 lbs.	107,748 lbs.	145,957 lbs.
Nipples, per mile	1323 "	1759 "	2410 "
Rivets, do	3823 "	2960 "	3427 "
Bands, do	5476 "	3418 "	4601 "
Lead, do	4717 "	6048 "	8215 "
Asphaltum, do	4542 "	5982 "	8197 "
Average weight per foot	30.7435 lbs.	24.226 lbs.	32.728 lbs.
Cost of pipe per foot run, including rings, but exclusive of bands and special castings, delivered at Vancouver	$1.53½	$1.35	$1.72½
Cost of unloading from scow at Capilano Wharf (lead and bands included) per foot run	2.3058 cts.	1.8169 cts.	2.4546 cts.
Cost of distributing along trench, lead and bands included, per foot run	10.4857 cts.	13.9191 cts.	21.6969 cts.
Cost of laying per foot run, including lead	0.13	0.13	0.17½
Total cost of pipe in trench per foot run	$1.792915	$1.63736	$2.141515
Number of rivets in nipple	4	4	4
Weight of same	$\frac{1}{16}$ lbs.	.078 lbs.	.078 lbs.
Total weight of rivets per length	15 "	13.359 "	15.468 "
Dimension of pieces punched out	$\frac{5}{16}'' \times \frac{5}{16}''$	$3.\frac{5}{16}'' \times \frac{11}{100}''$	$\frac{5}{16}'' \times \frac{11}{100}''$
Weight of pieces punched out	4.89 lbs.	398 lbs.	3.896 lbs.

DETAILS OF BENDS AND CASTINGS.

CAST IRON BENDS FOR 16 INCH MAIN.

Angle of deflection.	Number required	Weight of each.	Length of chord from bell to bell	Distance covered when in place in trench.	Cost of each at Foundry.
5 degrees	15	310 lbs	1′.11½″	5 7/32″	$10.85
10 "	28	409 "	1′.5½″	10 1/32″	14.31
15 "	16	487 "	1′.10″	15 3/32″	17.04
20 "	14	580 "	2′.2½″	20 1/16″	20.30
25 "	11	674 "	2′.6½″	26 3/16″	23.59
30 "	11	772 "	2′.11″	31 1/32″	27.02
35 "	9	870 "	3′.3″	36 1/32″	30.45
40 "	12	939 "	3′.7″	41 7/32″	32.86
50 "	4	1188 "	4′.3½″	52 1/32″	41.58
55 "	1	1267 "	4′.7″	57 1/32″	44.34
60 "	3	1347 "	4′.11″	62 7/32″	47.14
70 "	1	1490 "	5′.6½″	73 5/16″	52.15
90 "	1	1860 "	6′.7½″	94 1/16″	65.10

CAST IRON BENDS FOR 22 INCH MAIN.

Angle of deflection	Number required.	Weight of each.	Length of chord from bell to bell	Distance covered when in place in trench.	Cost of each at Foundry
5 degrees	12	470 lbs	1′.11½″	5 7/32″	$16.45
10 "	18	630 "	1′.5½″	10 1/32″	22.05
15 "	10	785 "	1′.9½″	15 3/32″	27.47
20 "	3	910 "	2′.2″	20 1/16″	31.85
25 "	3	1050 "	2′.6″	26 3/16″	36.75
30 "	4	1270 "	2′.10½″	31 1/32″	44.45
35 "	2	1435 "	3′.2½″	36 1/32″	50.22
50 "	1	1895 "	4′.2½″	52 1/32″	66.32

OBITUARY.

CECIL BUSHE FRANKS was the son of Mr. John Ferguson Franks, Barrister-at-Law, of Dublin, and a grandson of the late Chief Justice Bushe of Ireland. He entered the Royal Navy when a boy, but, owing to his defective hearing, he was obliged to retire, when he decided to devote himself to Civil Engineering. Going out to New Zealand, he was for a time engaged with a party of surveyors in making Government surveys. On leaving New Zealand he went to the United States, settling for a time at Buffalo, N. Y., and during the time he was there he was engaged in painting marine pictures.

About the year 1870, he moved to Hamilton, Ont., and entered the service of the late Great Western Railway Co., remaining with them until 1873, when he accepted a position on the Hamilton and Lake Erie Railway which was then under construction. Having continued with this Railway Company for some time, he resigned in order to form a partnership with Mr. Stanton of Hamilton as Provincial Land Surveyors.

In 1881 he was again engaged upon the Great Western Railway, and was connected with it and the Grand Trunk Railway up to June, 1888, when he resigned his position on account of ill-health. He then went to England for about six months, hoping to derive benefit from a change of air, but on returning to this country he was no better.

Soon after his return to Canada he decided to go out to South Africa, but on reaching England he was persuaded by his family to remain there for a time, and to undergo a course of medical treatment.

At the end of three months he was much improved in health, and he went to Rotterdam on a short visit. There he died suddenly on the 18th of October, the cause of death being aneurism of the heart.

Mr. Franks was an extremely well educated man, and a thorough mathematician. His circle of friends was very large, and being so honorable, upright and pleasant, he made friends wherever he went.

He became a Member of the Society on the 3rd of February, 1887.

E. E. GILBERT, one of the oldest and best known mechanical engineers in Canada, died of heart disease on February 12th, 1889. He was born in Montreal in 1823, and at the time of his death was sixty-six years of age. Like a great many engineers of the day, he did not receive early professional training. He commenced his career in the forwarding business at Montreal, and was one of the pioneers in trading by steamer to Chicago, and other then distant ports on the Great Lakes. Having great mechanical ability, he invented machinery for loading and discharging cargo on the vessels with which he was connected.

In 1858, he and the late Mr. W. P. Bartley entered into partnership as engineers. The firm carried on business in Montreal for several years, building a large number of engines for river and lake steamers, as well as machinery for other purposes. He afterwards removed to new works, which he carried on on his own account for many years, and where he constructed some of the largest engines for lake and river steamers in Canada, introducing many important improvements, particularly in the valve gear of marine beam engines.

He was, perhaps, the first engineer outside the United States to fully recognize the advantages of the "Corliss" valve gear, and as long ago as 1859 he had built and fitted a paddle steamer with a Corliss engine. In 1860, the steamer "Montreal" was built, having a Corliss engine with a cylinder 60 in. diam. and 8 ft. stroke.

In this steamer he introduced the forced blast for boilers, on the closed stoke-hold system, now in universal use on modern fast steamers in naval and mercantile marine. This steamer is still running regularly between Montreal and Quebec, and, after nearly thirty years, is still a fine specimen of marine engineering.

Later on in connection with his sons, he invented a new system of submarine rock blasting and excavation, and undertook extensive government contracts for deepening the rapids in the River St. Lawrence, all of which were successfully carried out under unusual difficulties. He devoted much attention to pumping engines for water works, and built engines for Toronto, Montreal, and other cities in Canada. One of his last examples was for the high level service of the Montreal Water Works. The engines were built from his own design, and their performance not only exceeded his own guarantee, but placed them amongst the best of high duty pumping engines.

He contracted a few months ago with the Canadian Government to execute works on the enlargement of the Cornwall Canal, and after visiting Ottawa on business connected with the work, he died suddenly of heart failure on arriving at his home.

He became a Member of the Society on the 20th of January, 1887.

LOUIS LESAGE, eldest son of Mr. Louis Lesage, of L'Epiphanie, L'Assomption County, Province of Quebec, was born on the 13th of August, 1827.

He was educated at the College of L'Assomption, which he entered at the age of twelve years. There he remained for about ten years, taking a complete course of classical studies, and devoting himself principally to mathematics, in which he excelled. About the year 1848, he had serious thoughts of entering the priesthood, and, with this object in view, he commenced the study of Theology at the Grand Seminary, Montreal and at Chambly. During a portion of this time he was associated with the present Archbishop of Montreal, as secretary to the late Mgr. Bourget.

In 1851, however, he decided to devote himself to Civil Engineering and Architecture, and spent some time in acquiring practical knowledge under Messrs. Labelle & Laberge, contractors, Messrs. Ostell & Perreault, land surveyors, and also under Mr. Bourgeau, then architect for the Montreal Court House, St. Peter's Church, and other important buildings in Montreal.

He was employed for a time on the survey for the Grand Trunk Railway, at Rivière du Loup, and on his return to Montreal, in 1853, he became assistant to Mr. Thomas C. Keefer, Past President of the Society, then engineer of the Harbour Works and the new Water Works of Montreal. Mr. Lesage henceforth devoted himself to hydraulic engineering, and in 1856, he was appointed Superintendent of the Montreal Water Works, which office he filled till his death, a period of 33 years.

From 1856, the history of Mr. Lesage's professional life is therefore the history of the Montreal Water Works. Up to this time, the city water had been supplied by small pumping engines at the foot of Friponne St., under the pressure due to the old reservoir on what is now St. Louis Square, with a distribution system which was inadequate and imperfect, even for that supply. The new aqueduct, with pumping machinery and reservoir for furnishing 6,000,000 gallons per day, at nearly double the effective pressure, had just been built and set to work. Mr. Lesage's first duty was therefore to remodel and enlarge the distribution to a scale corresponding with that of the new supply. Difficulties soon arose in supplying the rapidly increasing water consumption of the city, owing to the aqueduct and the River St. Pierre, which acted as a tail-race, becoming choked in winter with both frazil and surface ice, thus greatly reducing the head and quantity of water available for driving the pumping machinery.

To remedy this, Mr. Lesage, in 1865, added a turbine and pumps with a pumping capacity of four millions of gallons per 24 hours; the turbine being placed at such a level as to be little affected by changes in the head and tail water. In 1867, the pumping main was doubled, and the distribution had by this time been vastly enlarged.

Much relief was afforded by the new pumps, but the consumption soon again overtook the winter capacity of the supply, and in 1869 Mr. Lesage had recourse to steam pumping, mainly with a view to tiding over the winter difficulties.

In 1872, a second pumping engine of three million gallons capacity was added, and the tail race was lowered, so as to give increased efficiency to the water power machinery. Two years later, he further improved the water power machinery by the substitution of a turbine at low level for one of the original breast wheels. By this time, the average daily consumption had increased to 8,000,000 gallons per 24 hours, and to keep pace with it, Mr. Lesage added a Worthington engine of 8,000,000 gallons capacity, and also a 30 inch pumping main. For the supply of parts of the city not commanded by the main works, Mr. Lesage planned, and, in 1875, put into operation a high level system with a Worthington engine, taking water from the main reservoir and discharging into one of one and three quarter million gallons capacity, at 210 feet higher elevation.

Mr. Lesage, as well as other engineers, had already recommended that a beginning be made toward the construction of a new aqueduct, and soon afterwards the City Council gave the necessary authority. The first section of this was therefore undertaken and opened in 1877, the working being designed in such a way as to form a new entrance to the old aqueduct, and to almost entirely obviate its choking by frazil. About the same time, the reservoir was enlarged to 35 million gallons capacity instead of 13½ millions as at first.

In 1881, the water power machinery was strengthened by the addition of a turbine and pumps of 2½ million gallons capacity, and four years later the oldest of the steam pumping engines was taken out to make room for a high duty Worthington engine of 10 million gallons capacity. In 1885, the high level system was improved by the addition of a three cylinder Gilbert engine.

During Mr. Lesage's administration the Water Works thus grew from a single system, with a daily pumping capacity of 6 million gallons, to two systems of 34 million gallons, and from a daily consumption of two millions to one of thirteen and a half millions, with a corresponding increase in the extent of the distribution pipes and great improvements in every detail.

Mr. Lesage was a member of the American Society of Civil Engineers and of various other scientific bodies. He took a prominent part in the formation of the Canadian Society of Civil Engineers. He was elected a member of the first council in 1887, and continued in office until failing health compelled him to decline re-election. From 1880 to 1883 he was mayor of Verdun and chairman of the Board of School Commissioners.

On three occasions he rescued persons from drowning, and received the medal of "La Société des Chevaliers Sauveteurs des Alpes Maritimes."

Mr. Lesage was devoted to his profession, and his ability was recognized, not only by his more intimate associates, but also by many engineers with whom he came in contact, both in this country and in the United States.

He became an authority upon questions relating to Water Works, and he was consulted regarding the works at the following places in Canada: Ottawa, St. Catherines and St. Johns, P. Q., in 1871; Sorel, in 1872; Peterborough and St. Hyacinthe, in 1873; Three Rivers and Joliette, in 1875; Longueuil, in 1875–6; St. Henri, St. Jean Baptiste, Hochelaga and Berthier, in 1876; Windsor, N. S., in 1879: Sherbrooke, in 1881; Cote St. Antoine in 1885; St. Jérome in 1884, and Terrebonne in 1886.

As a public officer he was characterized by unswerving uprightness, broad, sound judgment, and much administrative ability. In private life he was a devout Catholic and was endeared to a large circle of intimate friends by his intellectual force, his kindly disposition and his irreproachable character.

He died at his residence at Verdun, a suburb of Montreal, on the 9th of January, 1889, in his 62nd year.

He became a Member of the Society on the 20th January, 1887.

WILLIAM E. COLQUHOUN.—The late William E. Colquhoun, only son of William Colquhoun, Esq., Ex-M.P.P. for the County of Stormont, was born at Dickenson's Landing on the 3rd April, 1865. He received his primary education at Cornwall Public School, and afterwards attended the High School of the same place, from which he entered Upper Canada College. He afterwards matriculated in Toronto University, and pursued his studies there for some time. In 1884, he entered the School of Practical Science, where he began a course of study in his chosen profession, Civil Engineering, and was preparing for his final examination when he was taken ill with inflammatory rheumatism. His parents were immediately summoned to his bedside, and although the best medical aid was procured, he died at the General Hospital on the 16th March, 1888.

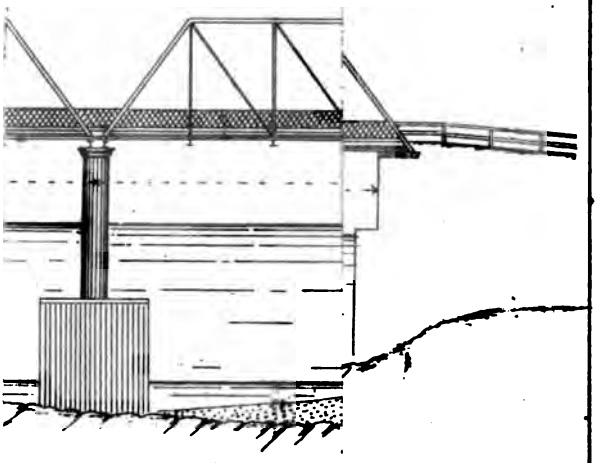
The deceased, who was of a very studious nature, was very successful in all his studies, and but for his untimely death would, without doubt, have figured prominently in his profession, to which he was devoted. His quiet and unassuming manner and warmth of friendship won for him the respect and esteem of all with whom he was brought in contact.

His diary, which remains in his father's possession, contains complete and minute details of the chief events of his life, together with many other incidents which came under his observation, and forms an interesting and valued relic for his relatives. While attending the School of Practical Science, the Canadian Society of Civil Engineers was formed, which he identified himself with, and became one of its charter members, being elected a Student on the 24th of February, 1887, and retaining membership up to the time of his death.

WILLIAM HAYWARD LOUGH, son of Mr. M. Lough, Provincial Land Surveyor, of Toronto, was born at Port Hope, on the 8th of November, 1863. He was educated at the High School of Clinton, Ontario, and in 1881 went to the Agricultural College, Guelph; but having no taste for farming, he left in 1882. He then entered the employment of Messrs. Langley & Burd, architects, of Toronto. As his journal shews, his great desire was to become an engineer. After about a year spent in Dakota for his health, he returned to Toronto and entered the School of Practical Science there. In May, 1884, he accepted a position in the Engineering Department of the Harbour Commissioners' Office, Montreal, where he remained until August, 1888, when failing health obliged him to return home to Toronto. His devotion to duty and to his profession, and neglect of himself, had evidently undermined his constitution. He soon ran into rapid consumption, and died at Toronto on the 19th of February, 1889.

He was elected a Student of the Society on the 25th of June, 1887.

ATE XII.



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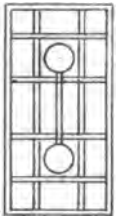

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TRANSACTIONS

OF

The Canadian Society of Civil Engineers.

VOL. IV.

JANUARY TO DECEMBER,

1890.

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PRINTED FOR THE SOCIETY

By John Lovell & Son.

1891.

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1896, March 16.
Scientific School.

The Society will not hold itself responsible for any statements or opinions which may be advanced in the following pages.

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PRESIDENT, CAN. SOC. C.E.
1889.

L. S. Lamley
Colonel. A.D.C.

PRESIDENT, CAN. SOC C.E.
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CANADIAN SOCIETY OF CIVIL ENGINEERS.

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Canadian Society of Civil Engineers.

SESSION 1890.

TRANSACTIONS.

Thursday, 2nd January.

P. A. PETERSON, Vice-President, in the Chair.

VANCOUVER WATER WORKS.

DISCUSSION.

Mohun. The author, in his very interesting and comprehensive paper, gives the average velocity of the Capilano River for the first seven miles from its mouth at five feet a second. A difficulty has been frequently encountered,—notably in the precipitous mountain ranges of the Pacific Coast,—in maintaining impounding reservoirs in somewhat similar situations. In these torrential streams it has been found that the boulders and gravel washed from the banks and bed above the dam are liable to be swept down and gradually fill the reservoir. A velocity of five or six feet a second will move good sized boulders, and less than half that velocity will move gravel. From the author's description of the bed of the stream, it would appear that the velocity has been great enough to remove most of the gravel from the channel, except at points where from the formation of the banks slack water was encountered. On the other hand, as even the most sanguine Vancouverites do not anticipate a population of four or five millions requiring a daily supply of 440 millions of gallons, a storage reservoir, as such, is not an essential, provided means are adopted to keep the entry conduit clear.

The steel mains which were built and laid by the Albion Iron Works Company of Victoria did not when first laid give satisfaction. Many were leaky, and considerable damage was done to the streets.

These defects have, it is believed, been since remedied, and the writer is informed that the same Company subsequently laid a similar main with complete success for the Victoria Water-Works. The writer understands that the Iron Works Company was solely responsible for making and laying the steel mains in Vancouver.

On the 15th November, 1889, a serious accident happened to the submerged main, by which the city was deprived of its water supply for eight days. One of the 12 in. cast iron pipes, lying in 40 feet of water, was badly fractured, and it can hardly be doubted, from the position of the pipe, that the break was caused by a water ram. The writer understands that Mr. G. A. Keefer had recommended automatic blow offs at each end of the submerged main, to guard against just such an accident; but unfortunately his advice had been neglected. The blow offs referred to by the author are not automatic. The break was repaired by a diver, who covered the fracture with a wrought iron sleeve, in two parts bolted together and lined with vulcanite. In justice to the Water-Works Company, it should be added that it did all in its power to reduce the inconvenience to a minimum, bringing water across the Inlet, and delivering it free to its customers by cart.

Having been resident in Vancouver at the time of the discussion of the rival water-works schemes, the writer is aware that the main objections raised to the Capilano project were based upon the supposed difficulty of crossing the Narrows. One party said that it could not be done, because no similar work on the same scale had yet been attempted. It is to be hoped that there are but few engineers with whom such a reason would have weight. The more reasonable opponents of the work did not dispute the practicability of laying the pipe, but thought that, in only having a single main, in the event of an accident to it, the safety of the city would be imperilled, putting on one side the terrible inconvenience of a short water supply. From Mr. Smith's paper it appears that the duplicate submerged main was a part of the general plan which hitherto the company has failed to carry out.

The writer has always believed in the feasibility of laying the submerged main, and has never hesitated to express this opinion to the opponents of the scheme. Looking, however, to the vast interests at stake, the has always insisted upon the necessity of the submerged main being in duplicate, and is glad to learn that since the accident the company has taken active steps towards laying on additional main across the Narrows. From the reports of the divers it would seem that the pipe has not been moved by the current from the position in which it was first laid.

With regard to the dangers to be apprehended from vessels' anchors, the writer is inclined to think they have been exaggerated; nevertheless, were he responsible for the maintenance of a single line of pipe across the Narrows, upon the integrity of which the very existence of the city might at any moment depend, he would be very uneasy until all human precautions had been taken to secure its safety. A simple mode of obviating any risk from ships' anchors would be to cover the pipe with concrete in sacks laid by a diver. This if done properly would also add greatly to the strength of the pipe; and if the diver's report, that the pipe was lying in a groove in the sandstone rock, is correct, the pipe, by the means suggested, would be completely incased in a shell of rock.

The unfortunate accident referred to has, for a time, put a stop to submitting to the ratepayers, a scheme for the purchase of the Water works by the city; and though the vast majority of the citizens are agreed that the city should own its water supply, no by-law approving of the purchase would pass, unless it was felt that such another failure was practically impossible. The burnt child dreads the fire. Vancouver has once been wiped off the face of the earth, and it cannot be wondered that her citizens should refuse to purchase a system, which, under the same circumstances as occurred a month or two ago, would leave them at the mercy of a conflagration which might occur at any moment.

Mr. P. Summerfield.

The conception of the Capilano Water-Works for the supply of the city of Vancouver was of its very nature one of the best examples of hydraulic engineering to be met with on the Pacific Coast of the Dominion. The great difficulty to be encountered was the crossing of an arm of the sea under conditions entirely unparalleled in water-works engineering, and in some respects the pipe line across the Narrows of Burrard Inlet is almost without an equal.

The design of Mr. G. A. Keefer, M. Can. Soc. C. E., for the Capilano Water-Works was not the only design for Water-Works for the city of Vancouver.

The Coquitlam Water-Works, designed by Mr. E. A. Wilmot, M. Can. Soc. C. E., was also under consideration at the same time that the Capilano Water-Works was being matured, and as both projects received a great deal of consideration at the time, their merits and demerits being frequently discussed both in the press and elsewhere, it may not be out of place for an outsider to present the features of both schemes to the Society of Civil Engineers. The data before the writer are the

reports by Col. W. R. Eckhart, of San Francisco, on the Capilano River Scheme, and which is now constructed, and the Coquitlam Lake Scheme, which is now being matured for the supply of the city of New Westminster, reported upon by Mr. H. Schussler, chief engineer of the Spring Valley Water-Works of San Francisco.

The elevation of the pipe inlet as given by Mr. Eckhart for the Capilano was 422 ft.

The elevation of the pipe inlet, as given by Mr. Schussler for the Coquitlam, was 435 ft., so no important difference obtained between the elevations of the two proposed systems.

The entire length of the Capilano scheme, as given by Mr. H. B. Smith in his valuable report, is 52,741 ft. from the dam to the centre of the city, or very nearly 10 miles.

The entire length of the Coquitlam scheme as given by Mr. Schussler is 105,600 ft., or 20 miles.

It will thus be seen that the laying of the submerged pipe across the Narrows of Burrard Inlet was the direct means of saving 10 miles of piping so far as Vancouver water supply was concerned.

Mr. Thomas C. Keefer, C.M.C., Past President of the Society, reported upon the Capilano scheme; and looking now upon the accomplished work, the only feeling is one of admiration for the design of so bold an engineering feature as the submerged pipe line across Burrard Inlet Narrows. For a country or carrier main, mild steel enables the engineer to undertake works of magnitude, that, if he were compelled to use cast iron mains, would almost render the cost of such works prohibitive.

At present ruling prices, a steel main of equal dimensions can be laid complete in the trench for about the same figure that a cast iron main could be landed on the wharf in Vancouver or any other port on the Pacific Coast; thus shewing clearly that it is possible to effect a saving of nearly 40 per cent. in the cost of the pipe line. But valuable as mild steel is for mains of large dimensions, there appears to be a tendency among engineers to exact too much from it.

Thus in the Vancouver Water-Works system, the ultimate strength of the 16 inch main, allowing a tensile strength of 60,000 lbs. per inch for plates, and .7 for strength rivetting, would be 580 lbs. per sq. inch, and the same data for the 22 inch would permit of 420 lbs. per sq. inch. Now, according to Mr. Smith's report, the 22 inch main has to sustain a head of water equal to 164 feet in height or a pressure of 71.17 lbs. per sq. inch, as a maximum. The factor of safety in this case is therefore 6.

In the case of the 16 inch main, the head of water sustained is

equal to a column of 415 feet, and equal to a pressure of 180.11 lbs. per sq. inch as a maximum. The factor of safety in this case equals a little over 3 or nearly 3¼. It is apparent therefore that no very great amount of corrosion can take place without very materially reducing the factor of safety, and that moreover the workmanship and material must be the best obtainable.

From Mr. Smith's report there is a flush valve on the 22 inch main, and likewise one air valve in the tunnel. On the 16 inch main there is a flush valve on the north side and another on the south side of the Inlet, one air valve located between the Inlet and Coal Harbor, and two flush valves on opposite sides of Coal Harbor.

The total number of vertical and horizontal bends are given by Mr. Smith at 179. It would be interesting to know how many of these are horizontal and how many vertical bends; for no matter how free from sediment the waters of the Capilano may be, there are certainly a great number of elevations and depressions without either air or flush valves, and doubtless there will be a great difference of opinion as to the capacity of the 16 inch main after accumulations of air and silt have taken place.

From the description of the turning on of the water, it is very evident that water-ram and air compression were treated as a myth, and it would afford a great deal of valuable information if Mr. Smith would give a detailed account of the behaviour of steel mains, having a factor of safety ranging from 3 to 5, a large number of angles of elevation and depression along the pipe line, few air valves and very few flash valves, with a full head of water flowing with a velocity of 1.4 feet per second. The water seems to have taken 3¾ hours to traverse 19,320 feet from the tunnel to the north shore of Burrard Inlet. That something occurred may be inferred from the last two paragraphs of Mr. Smith's paper.

It appears that a tank is now placed on the north side of the Inlet at an elevation of about 230 feet above tide water mark, thus reducing the pressure upon the lower portions of the system by 200 feet of head, and likewise reducing the pressure upon the upper portion of the system by the difference between the velocity and static pressures, as the tank is allowed to flow over and to discharge the surplus water into the river. Some kind of provision is made for inserting a plug so as to utilize the full head of 430 feet in case it should be required.

Taking Mr. Smith's description of the Vancouver Water-Works, one cannot help feeling that there can be no difference of opinion about the works as projected by Mr. Keefer, for they are without a doubt unri-

valled in this section of country; but there is a wide field for discussion relative to the manner in which Mr. Keefer's plans have been carried out. Doubtless other engineers who are conversant with the question will give us the benefit of their extended and valuable experience on this very important branch of engineering,—water-works construction.

Mr. D. J. Russell Duncan.

The writer has read the advance proof of Mr. H. B. Smith's paper on the Vancouver Water-Works with very great interest, and as copious extracts have been made from a small pamphlet, which the London Steel Pipe Co. published a few years ago, and the joint referred to in that pamphlet is described on page page 338 (Vol. III) of the author's paper as a *cumbersome arrangement*, the writer desires to bring under the notice of the Society some particulars with reference to this joint.

The advantages of a single socket, as compared with the Moore & Smith joint, are the great reduction in the quantity of lead consumed, the adaptability of the joint to overcome angular deviations in the pipe track, and the increased strength of the spigot, which must be of sufficient firmness to resist the strains due to caulking by inexperienced workmen.

The Moore & Smith joint, although it has no doubt been very largely employed, is inferior to the joints referred to, because the nipple reduces the internal diameter of the pipe, and tends to create an increased velocity of the flow of water through the pipe and the joints; whereas the joint now referred to is so constructed, that the pipe is actually larger in internal diameter wherever the joints occur, and this system of construction is of decided advantage by reducing the friction of flowing water.

It cannot be fairly said by the author that the joints to which the writer refers have been entirely discarded on the Pacific Coast, for the simple reason that they have never yet been employed there, with the exception of the pipe line constructed by the Steel Pipe Company, Limited, London, for the water supply of the town of Mazatlan, Mexico. This is the first pipe line on the Pacific Coast fitted with the improved joints, and is a line 20 miles in length and 14 and 12 inches internal diameter.

With regard to the 22 inch and 16 inch pipes, it is a matter of some surprise that these pipes were specified so thin. The pressure upon the pipe line is about 400 feet near to the Burrard inlet, and the pipes at this point are 16 inches diameter, and .11 of an inch in thickness. So far as the writer's investigations go, the ordinary

working pressure on a Californian wrought iron pipe of this thickness and diameter would not exceed about 265 feet head, and according to the practice of this company, pipes of this thickness would not be made of mild steel for a higher pressure than 285 feet. It is clear therefore that the pipes laid by the Vancouver Water-Works Company are subject to much higher strains than is customary, and there is every reason to believe that the life of the pipe will thereby be injuriously affected. The paper gives no information regarding the test pressures imposed upon the steel pipes, indicating that the cast iron connections only were tested to a pressure of 300 lbs. per square inch.

It is unfortunate that the author has not given details of the riveting. On the 2nd of May, 1889, this Company received a long letter from him, indicating that the pipes leaked to such an extent that when the water was turned on it was found impossible to stop them. In his letter dated April 13th, 1889, he says: "In two days time it was discovered that the leaks were enlarging, and the plates being actually cut by the jets of water forced out between the laps. The holes made in this manner are just beyond the edge of the outside lap, and are of all shapes, some being circular and nearly half an inch in diameter. After the pressure the appearance presented by the pipes was as if they had been acted on at several points by a sand blast." He then goes on to state that attempts were made to repair the leaks by cast iron rings; but on again subjecting the pipes to pressure, new leaks were developed, and at the date of his letter 5,700 feet of the pipes were leaking so badly that their removal was ordered and new pipes decided upon.

It is somewhat misleading to read in the latter paragraphs of the paper that the leaks discovered at the seams were speedily repaired by steel rings four inches wide, made in halves, which were made to go round the pipes, in the face of the information contained in the letter of the 13th April, to which reference has been made, and the writer would suggest that the author should correct the latter part of his paper.

In replying to the author's letter about the leaks, the following questions were asked, and it is very desirable that the information should be communicated to the Society:

Were the rivets put in hot or cold?

Were they closed by power, and if so by what power?

How were the longitudinal seams distributed round the circle?

What was the length of the rivets?

Were any sections of pipe rivetted up and tested by hydraulic power in excess of the working pressure, to prove the quality of the rivetting, and was any test whatever made of the rivetting?

With what were the pipes coated, and how was the coating applied?

How were the pipes jointed together?

The length of pipes being 23 feet, 9¾ in., seven plates was a very large number to employ. Four would have been preferable, thus saving a number of rivetted seams.

The rivetting was apparently faulty and the plates not properly laid together at the seams, and possibly burrs were left at the rivet holes which prevented the perfect contact of the surfaces.

Although a rivetted joint may be made strong enough to resist the strain brought to bear upon it by a tension testing machine, and may be proved to be very nearly equal in tensile strength to the original plate, yet the rivets may not be close enough to secure water tightness under pressure. Experience has proved that there is considerable difference between pipes being strong enough to resist a certain tensile strain across the joint, and being water-tight under fluid pressure, which may exert no greater tensile strain across the joint than that for which it was designed. The evidence submitted at the time, led this firm to the opinion that the defects in the pipe were due to faulty workmanship and inexperience on the part of the contractors.

No information is given in the paper as to the means adopted for letting off air in the pipe, and possibly the leakages which were found were aggravated by the accumulation of air in the mains before the pipes were properly filled with water. Neither is any evidence given as to the hydraulic tests upon specimens of the pipes to prove the tightness of the rivetting.

The writer considers it bad practice to make up the pipes of so many small plates. It is found much more satisfactory to make the plate cylinders in lengths of from 6 to 8 feet; and if this system had been adopted for the steel pipes described by the author, there would have been a great reduction in the number of circumferential rivetted seams.

Caulking, in the manner described by the author, tends rather to aggravate leaks than to prevent them whenever mild steel plates are employed. A better system for preventing leakages and to make perfectly water-tight joints is to employ suitable plate closing apparatus upon the rivetting machines, the effect of which is to close the plates perfectly together, so that the laps are thoroughly overlaid and the surfaces brought into close contact before the rivets are inserted; then when the rivets are closed by hydraulic pressure there is no liability to leakage, and caulking is entirely dispensed with.

The description of the method in which the lead joints were made is such as to indicate that the work of making a Moore & Smith joint is at least twice as much as that of making the patent socket joint recommended by the writer. The great care which has to be taken in making the Moore & Smith joint in a perfectly straight line is a very serious disadvantage. A particular feature in an efficient joint should be its facility for overcoming angular deviation in the pipe line, and thereby reducing the number of bends.

It may be mentioned that a 9 inch steel pipe, which was laid by this firm in the Tay Viaduct some years ago, was laid round a very sharp curve on the bridge, without any special connections whatever, the flexibility of the joint permitting the curvature of the pipe line. The joints were made above ground, and 360 feet of jointed pipe in a single curved line lowered into the trench.

Nor is there any necessity in a joint such as is recommended for the caulkers to be cautioned with regard to the packing of the lead. The spigot ends of the pipes are welded into cylinders, and made about 50 p.c. thicker than the pipe, so that any pressure the caulker imposes upon the lead will not indent the pipe, or in any way cause it damage. The sockets for pipes up to 24 inches diameter are stamped by hydraulic pressure on the system invented by Mr. James Riley, General Manager of the Steel Company of Scotland, Limited. This is known as the Riley Patent Socket. This socket has an external lip or flange which adds very greatly to its strength, and with this joint it is not found that the shell of the pipe is bent inward nor the mouth of the socket bent outward, as is the case with the Moore & Smith joint, described by the author on page 339 (Vol. III) of his paper.

With regard to the system of constructing pipes with inner and outer courses, this method is entirely discarded by this Company on pipes of all diameters made of plates under .2 of an inch in thickness. A much more correct and reliable method of making perfect circumferential seams is obtained by the use of suitable machinery for expanding the circumferential lap at one end of the plate cylinder, after the plates have been punched and bent into cylinders; all the circumferential seams are carefully punched by multiple punching machines precisely to the same pitch, and the increase in pitch due to the enlarged diameter of the overlap is obtained by stretching the plate in the manner described.

For pipes made of plates exceeding .2 of an inch thick, the circumferential seams of the outer course are punched when the plate is flat, by dividing machines which divide the pitch into the most minute fractions

necessary to overcome the irregularities between the diameter of the outer and the diameter of the inner course of plates. The system described by the author, of leaving one end of the plate cylinder to be punched while the pipe is rivetted up in the pipe track, is not only one which causes enormous delay in the execution of a pipe contract, but one which is liable to very great inaccuracies of workmanship. The method described of fitting the pipes together in a trench, drawing them apart, punching the holes, putting them together again, and rivetting them up is most unsatisfactory.

With regard to the distribution of the longitudinal or straight seams, a pipe made of very thin plates, such as those employed for the Vancouver Water Works, is made stronger and better by a uniform distribution of the longitudinal seams of the several courses around the circumference, instead of having them all in one straight line. Sometimes in constructing pipes with the longitudinal seam all in one line along the pipe, much greater care has to be taken in straightening the pipe, as there is a tendency to curvature.

The paper is one of very great interest to all engineers interested in water-works, and the author has displayed conspicuous ability in the execution of the works under his charge.

Mr. G. H. Henshaw.

Mr. Henry Badeley Smith's able paper on the construction of the dam and pipe line of the Vancouver Water Works leaves little for the critic to say, beyond expressing admiration for the successful manner in which difficulties both novel and otherwise have been met under exceptional circumstances. The moderate height of the dam no doubt permitted the foundation (in the absence of puddling clay) to be laid with safety in the manner described; nevertheless, the accident to the "lean to," and one of a similar nature that occurred previously to another part of the structure, would seem to be a warning in case it should be proposed at any future time to increase the height of the dam.

With regard to the objections and answers to the plan of laying the pipe across the Narrows of Burrard Inlet, a few remarks may be in order.

The first objection begs the question by claiming as known a force that is not known, while the answer claims a mathematical demonstration not given, but doubtful in its fundamental basis, as all calculations of the forces of the sea must be without actual previous experiment.

The true reply to the objection is philosophical not mathematical. The bed of the inlet at the point of crossing is stated to be composed of soft sandstone, partially covered with mud, gravel and cobble stones. Now a stream with no friction on the bottom, other things being equal, would

flow with equal swiftness at every depth, hence the difference in speed between the bottom and top would be a measure of the friction at the bottom. But the present case is one of a tidal current, whose efflux and reflux are governed by so many and complicated conditions, extending even to the existence, occasionally at least, of an outward current at bottom and an inward current at top, that even the most careful observation would fail in producing reliable formulæ. It is plain then that where the erosive force is actually unable to remove mud, gravel and cobble stones, a 12 in. metal pipe would lie undisturbed, quite independent of its self-made trench. This argument also answers the second and sixth objections. The third has a little more in it, and is more weakly replied to. It is decidedly doubtful whether such a pipe could resist the direct impact of a falling anchor, or that any engineer would invite a trial; nor is it likely that he would be free from anxiety should a vessel, whose anchor fluke embraced the pipe, be caught in a violent gale. It would be interesting to see what mathematicians would make of the problem. The wisest course would seem to be to protect those parts which are not sufficiently trenched already in the bottom. The fourth and fifth are speculative, and need facts capable of clear verification in their support before they have a right to claim notice. The seventh and eighth are mathematical, to which a very decided practical answer has been given. The ninth objection is of unascertained antiquity, and is still voiced wherever old settled habits of thought are disturbed by new ideas. "Who ever heard of such a thing?" "Don't take much stock in these new fads," etc.

It is true that it is sometimes difficult, without giving more attention than is convenient, to decide whether a certain scheme is the work of a "crank" or of a scientific mind, but if it is worth considering at all, it is surely the duty of critics to meet arguments with something more than mere assertion, and to support their own statements on facts and premises which are undisputed or capable of ready proof. Mr. Smith is to be congratulated on having contributed such an interesting paper to the Society.

Mr. Peterson. As the paper is a long one, it will be better to discuss that portion relating to the dam this evening. If the paper is all read through at once, the points relating to the dam will probably be forgotten by next evening.

Mr. Blackwell. Was there not some mistake about the size of the tree? It would be hard to get the stumps out.

Mr. C. L. Smith. The author was perhaps a little misleading. The tree must have

been one badly formed at the root. He did not think there was a tree of that size solid right through.

Mr. C. E. Goad. It was a rare thing to see a tree solid right through there. The paper is well written and the subject elaborately gone into. There seemed to have been great difficulty in regard to the carriage of material, etc., but this matter could not be followed out properly without being able to see how the plans were adapted to the peculiar formation of the ground.

Mr. Peterson. It would have been much better had a large sketch been made showing the most important points of the dam, etc., and the methods taken to prevent the water following through the longitudinal timber, which is a great source of trouble in all works of this kind. As he understood it, in this case the water was kept back by sheet piling. Then there was the question of getting round the end, also a difficulty that had been overcome by a brush and gravel bank, but he did not understand how the concrete was put in. It would be a good plan to make a rule, such as was in force in the Institution, that all papers should be accompanied with large drawings which could be hung on the walls. This would very materially tend to aid the discussion.

Prof. Bovey. In reading the paper over, it would seem that some of the concrete had been made by mixing a certain amount of cement with gravel, out of which stones over a certain size had been eliminated. This was contrary to the practice recognized by many eminent authorities, who said that the best concrete was made of stones of irregular sizes—not limited to 1½ inches.

Mr. Gower. The material was different from what we had here. Take the London gravel, which was similar to that they had in Vancouver, and the practice was the same. All big gravel was taken out. It was more of a sea gravel than anything else, and generally it ran 1½" to ¾," and with a fine kind of grit was mixed six to one with Portland cement. This plan was invariably adopted by engineers in the south of England.

Prof. Bovey. The best concrete was made of gravel of different sizes—the more irregular the sizes the better. As to limiting the size of the gravel, some engineers say that large blocks of stone can be put in without injuring the concrete in the least.

Col. Hayward, City Engineer of London, in his specification for gravel, specifies for a small gravel nothing larger than 1½," mixed in proportion of six to one. Mr. Gower.

The idea of having stones larger than 1½" taken out was probably because the concrete had to go into a small space and had to be rammed. In filling large spaces there was no question but that large stones, two or three feet square, might be put in. In the Lachine bridge they put large masses of concrete—20′ × 40′ × 15′—in the middle of which they might have put large stones and filled in all round them, and in many cases stones larger than 1½" were put in. In the case under discussion, however, they were quite right in taking out everything over 1½," for the reason that they had to pack the cement, and it would be much easier to ram and make a much better job with small stones than with large ones. Mr. Peterson.

The timber in Burrard Inlet would in all probability be affected by worms. He did not know to what extent the Teredo Navalis had appeared on the Pacific coast. Some member present might be able to say whether any information had been obtained on this subject. Prof. Bovey.

Had seen specimens in the Library of the House of Commons at Ottawa, showing the effect of the "Teredo Navalis" on the timber of the Pacific coast, which is very disastrous. It had occurred to him what a fortunate city Vancouver was as compared with other towns having the average system of water-supply and cost of same. In Vancouver they had an abundant supply of cold, clear, running water for almost nothing. He imagined that if these works had been economically carried out, there would be a supply of water for all time at a cost of from one to two dollars per head per annum. There was a pressure of 80lbs. at the highest part of the town, which was remarkable. Mr. Blackwell.

In the harbour of Vancouver, on Burrard Inlet, piles of 18" diameter are eaten through sometimes in a year, and in a sawn section one can scarcely find half a square inch in any one place of solid wood. The holes are ½" in diameter, and some probably larger. The wood is just as if it had been perforated with a series of auger holes. He felt certain the teredo would never reach the dam, there is a great elevation with a very heavy current. They did not find them even where the water was brackish. Mr. Peterson.

Prof. Bovey. It had been stated that good cast-iron would resist the action of salt water, but he did not know of a case on record in which it had been found to do so. In a case that had come under his own notice columns taken up from foundations in salt-water were just like sponge.

Mr. Blackwell. He had not had much experience with cast-iron in salt water, but had seen cast-iron taken out of columns or piers just like cheese. That was the ordinary gray cast-iron of foundry casting. He would like to know something more about these pipes, which he believed were made in Glasgow. The sheet steel pipes had ends rivetted on which were described as "white cast-iron." There must be something more than that, because if simply white cast-iron they would be of no use at all; they would be like glass, having no tensile strength. In Glasgow there were several firms which made a specialty of producing a metal called "McCaffie's metal"—a sort of white metal. In the first place when cast it was like white pig, and was then decarbonized in a furnace, which converted it into a kind of semi-steel. If simply white metal they would not be fit for the purpose. It might be assumed that these joints were made of a material superior to ordinary "white pig" or "white cast-iron." A little more information regarding these joint castings would be interesting.

Mr. Peterson. Plenty of white metal water pipes could be obtained from Scotland and the north of England. He had got some out of pure white metal, which were nearly useless.

Mr. Blackwell. White metal was useless, as it had so very little tensile strength.

Mr. Peterson. When in Vancouver last year he saw this cast-iron pipe, a portion of the wrought-iron pipe, and also the valve that was placed between the cast and wrought iron pipe. There was a very heavy stream of water pouring out, and he was told that the wrought-iron pipe was not sufficiently strong to stand the pressure. Its thickness was less than $\frac{1}{4}$"—about $\frac{3}{16}$", and the rivets, he imagined, were about 4" or 5" apart. It was a very thin plate, and the water was flowing in little streams out of nearly all the joints of the sides. He believed that they had since put straps round the pipe to hold it together, but they had reduced the pressure by means of a safety valve. He was astonished to see the small size of pipes which had been put in for mains, viz.:—4" and $2\frac{1}{2}$", and he thought this was a mistake. He considered streets should have nothing less than 6" pipe, that is in places where there was to be fire protection.

A 4″ pipe was not large enough, and a hydrant on a 2″ pipe, in the case of a large fire with three streams going, would be utterly useless—there would be no water. It was, however, a case where the water supply was furnished by a company, which he thought should never be done. There can be no possible reason why every city or town should not build and own its water works. The corporation can certainly borrow money at a lower rate of interest than any company, and can afford to put in just such distribution of pipes as are wanted, and the corporation will then have complete control of its own streets. He knows of no instance where corporations have been supplied by water companies in which the supply has not been unsatisfactory, or in which the cost to the citizens has not been greater than if they had had a much more liberal supply under their own control.

Mr. H.B. Smith

In reply to the remarks of Mr. Mohun, the bed and banks of the Capilano having been, for ages past, swept by flood currents of great velocity, all loose boulders have long since been carried away, leaving the larger boulders so interlocked that it is rarely, and only in extreme floods, that one is loosened and carried down stream. In the course of years, it is probable that detritus from the banks may lodge itself in front of the dam; but, should this accumulate to any inconvenient extent, it can be readily removed, and at small expense. In the ordinary quiescent state of the river, when the current does not exceed 5 miles per hour, it is not probable that stones or good-sized boulders, as suggested by Mr. Mohun, are in motion along the bed of the stream. Smeaton's observations go to prove that a velocity of 11½ feet per second will not derange quarry rubble stones not exceeding half a cubic foot.

The considerations which decided the construction of a dam and reservoir at the point of supply were as follows:—A pressure as nearly uniform and invariable as possible would be obtained. There would be a direct gain of 11 feet of head, which would allow the system to be carried through the rock bluff at the end of the 22 inch main, by means of a tunnel of moderate length. To obtain the same head without a dam, the 22 inch main would have to be extended at least 1,500 feet further up stream, under conditions which presented features especially unfavourable for pipe laying, and for the permanency of the pipes when laid. By reference to plate XVI., it will be seen that, at a point 1,500 feet above the present dam, the channel of the river is not confined to one permanent position. Moreover, as the eastern branch, at the present period, is dry at low water, and the island between the

channels is invariably flooded at high water, an extension of the 22 inch main above the dam must necessarily cross the western branch to its western side, and following that side, where the banks are high and rock in situ is exposed, reach a point where works for an entry conduit of a safe and reliable character, during all stages of the river, would be of a costly nature.

Finally, as the Capilano is a stream which has only become known since the construction of the water works, reliable data as to the lowest possible stage of water are still wanting. It is impossible to say with certainty what changes in its volume may occur in the future; more especially when it is taken into account that its banks may be denuded of timber by forest fires and the improvements of settlers, and that at any season the snowfall in the mountains, on which its very existence depends, might be very much less than it has ever been known to be. Giving due weight to these considerations, no doubt Mr. Mohun will acquiesce in the opinion that the dam is a very valuable addition to the system.

Several lengths of steel main in the low lying parts of the system subject to full head, when first laid, developed leaks more or less annoying. These leaks were, however, overcome in the usual manner, by means of cast-iron lugs, leaded and caulked, and by the substitution of new lengths where the originals were leaky enough to warrant this step. The Iron Works Company, who furnished the pipes, under contract for manufacturing, laying, and maintaining the line of mains for two months after completion, were solely responsible for the leaks; and it is worthy of note that the substituted lengths, made by them from the same design as the original leaky ones, were found to be entirely satisfactory, showing that the leaks in the original lengths arose, not from the character of the pipes used, but from some fault in the construction of these lengths. The Victoria Water-Works, for which the same company subsequently made and laid a main exactly similar in all its details, is no parallel case, the total head of that system being under 200 feet.

When the break in the submerged main occurred, the writer was in England, and can give no account of it from personal knowledge. All the evidence in his possession goes to prove that it was a break pure and simple, due to a severe water ram created by a too sudden closing of the hydrants, and acting upon a defective pipe casting. The outer and inner skins of the metal at the point of rupture were found to be as perfect as on the day of immersion, 15 months previously, proving conclusively that the action of the salt water had had no deteriorating

effects. There appeared, however, in the centre of the fracture, a globular mass, showing a check by cooling or some other cause, which had prevented a proper fusion of the metal during the process of casting. The fracture beyond the flaw showed the hard, close-grained, white surface of a casting of good quality.

Inasmuch as there has been a great diversity of opinion, and so much has been written and spoken as to the possibility of repairing a break in the submerged main, it is fortunate that this accident occurred at the time it did, as it has demonstrated beyond question, even to the most sceptical mind, that this part of the system can be got at and repaired almost as readily as any other part. Although, on this occasion, the city was deprived of its water supply for a period of eight days, this was not due to the difficulty of effecting actual repairs, but to the unusually stormy weather which unfortunately prevailed at the time of the occurrence, preventing the company's divers from locating the leak. As soon as this was done, the necessary repairs were accomplished within 24 hours. Under the ordinary summer and winter conditions appertaining to Burrard Inlet, any similar leak can be repaired in the same or possibly a less period of time.

There can be no doubt that had Mr. Keefer's recommendation (that automatic blow-offs be placed at each end of the submerged main) been adopted, the possibility of a break from water ram, even under the conditions described, would have been greatly lessened; and had the general plan of the system been carried out in its entirety before the works were put in operation, such a break would have caused no inconvenience whatever to the city. It is even doubtful whether the citizens would have been aware of its occurrence. By referring to plate XVIII, it will be seen that the general plan provides for duplicate mains at the Narrows—one of cast-iron (laid) and one of steel (to be laid). Without presuming to criticise the action of the company in not having completed the crossing of the Narrows, as designed, up to the time of the break, there can be no doubt that it would have been well had they done so. At the same time, it must be conceded by all disinterested parties, that, as Vancouver is a young city, with as yet a small population, the citizens deserve every credit for the energy already displayed, and for the confidence they have expressed in the future progress of the city, by risking so much private capital in completing the system all but this one link, the more so as the chance of a break was infinitesimal. Since the occurrence of the accident, pipes have been ordered and tenders invited for the laying of the duplicate main.

The method proposed by Mr. Mohun, for protecting the single sub-

merged main from ships' anchors, is not a new idea. From the inception of the scheme, it was intended, should circumstances render it advisable, to insure the safety of the pipes by a covering of concrete in sacks. In the present instance, however, the pipe shell being of great strength, and to a large extent imbedded in the soft sandstone bottom of the Narrows, it is a matter of opinion whether such a costly addition to the works would have been advisable; the more so, as the author is not aware that this or any other protection has been adopted in the case of the submerged mains of other systems.

Mr. Summerfield is labouring under a misapprehension when he quotes the Vancouver Water Works system as an example of the tendency amongst engineers to exact too much from mild steel. To make good this assertion, he has endeavoured to show that the factors of safety of the 22 inch and 16 inch mains are respectively 6 and $3\frac{1}{4}$, assuming the ultimate tensile strength of mild steel at 60,000 lbs. per square inch, with a loss of 30 per cent. for double rivetting, and that, with these factors of safety, no great amount of corrosion can take place.

The tensile strength of the mild steel employed in the construction of the mains in question is, as per contract, 72,000 lbs. per square inch; 60,000 lbs. being little more than is ordinarily allowed for rolled wrought-iron plates of the best quality. The double rivetting of the horizontal seams has been so designed that 75 per cent. of the full strength of the plates has been retained. The ultimate strength of the 22 inch main $\frac{11}{100}$ of an inch thick is, therefore, 540 pounds. This main, being subject to a maximum pressure of 71 lbs. per sq. inch, has consequently a factor of safety against rupture at the horizontal seams of $7\frac{6}{10}$ instead of 6.

The ultimate strength of the 16 inch main, $\frac{11}{100}$ of an inch thick, is 743 pounds. The maximum pressure it is called upon to withstand at its lowest levels (which it may be here mentioned form but a small part of its whole length, and are so situated as to be easy of access both for inspection and repairs) is 180 pounds per sq. inch. Its factor of safety against rupture at the horizontal seams is, therefore, $4\frac{13}{100}$, instead of $3\frac{1}{4}$.

These calculations refer to the ultimate strengths of the mains at their weakest part, namely, the double rivetted horizontal seams. As far as corrosion is concerned, and this is what Mr. Summerfield more particularly refers to, the seams, being of two thicknesses of metal, are the strongest parts of the pipe. The shell will be the first to give way under this cause; and, in calculating factors of safety with reference to corrosion, the full strength of the plate must be allowed.

These factors may readily be ascertained to be 10 and 5½ for the 22 inch and 16 inch mains, respectively. The author is of opinion that these results give satisfactory evidence of the permanent safety of the mains, and in support of this opinion would mention, that in the Pacific States of the Union long systems of rivetted wrought-iron pipes have been in constant and satisfactory use for many years, under pressures sometimes as great as one-half their ultimate strength.

In connection with this subject, the following table, showing the strengths and pressures in the various parts of the Virginia City, Nevada, supply main, 11¼ inches diameter and 37,000 feet in length, may be of some interest.

VIRGINIA CITY, NEVADA, RIVETTED WROUGHT-IRON SUPPLY MAIN.

Ultimate strength 55,000 lbs. per sq. inch, less 30 p.c. for double rivetting.

Head in feet.	0 to 200	200 to 330	330 to 430	430 to 570	570 to 700	700 to 950	950 to 1050	1050 to 1250	1250 to 1400	1400 and over
Extreme pressure in lbs. per inch.....	87	143	187	247	304	412	456	543	608	750
Thickness in inches....	.065	.072	.083	.109	.120	.148	.180	.220	.259	.340
Ultimate strength in lbs. per sq. inch.....	435	482	556	724	803	991	1205	1473	1734	2276
Factor of safety.....	5	3.4	2.96	2.93	2.64	2.40	2.64	2.71	2.85	3

It may be here incidentally mentioned that, in a recent publication of the London Steel Pipe Company, issued under the auspices of Messrs. Russell Duncan and H. C. Mylne, Associate Members Inst. C.E., it is stated: "Wrought-iron pipes have been extensively used in the States, and it has been proved that no risks are run from fear of corrosion. Hundreds of miles of wrought iron pipes have been used for periods extending to over 30 years, and no indications are shown of injurious oxidation. In some cases the pipes have been used without coating of any kind, in others they have been coated with natural asphaltum, which is the common method of coating pipes in the United States. Under ordinary conditions, the coating of natural asphaltum is not affected by water, earth, or atmosphere."

In May of this year, 1890, 14 months after the opening of the Vancouver system, an official examination of the steel mains was made for the purpose of ascertaining to what extent corrosion had taken place. The earth covering was removed at numerous points along the line, and the pipes and castings closely examined without an indication of oxidation being found.

The number of horizontal bends in the 22 inch main is 33, and in the 16 inch main 103. Of vertical bends the 22 inch main has 20, none of which exceed 10 degrees deflection; and the 16 inch main 23, none exceeding 15 degrees deflection. As is the case in all properly constructed systems, every elevation of any magnitude is tapped by an air-cock; a fact, which, though not mentioned in the paper on the Vancouver Water Works, was so obviously necessary, that it might have been taken for granted. The profile of the 22 inch main from the dam to the blow-off at the tunnel, a distance of $2\frac{1}{2}$ miles, is very uniform. Naturally the greater part of any sediment brought down from the well chambers will be deposited in this main. The 8 inch blow-off is amply sufficient to flush it when required.

The greater number of the vertical bends in the 16 inch main are located in the first 8,000 feet beyond the tunnel, where the pipe line passes over unavoidable sidehill. Whatever small proportion of sediment may be carried past the deep depression, where the blow-off at the tunnel is situated, into the 16 inch main, will be of minute particles, and will have little opportunity to settle in the bends, inasmuch as the velocity of flow in that main is $5\frac{6}{10}$ feet per second, a velocity amply sufficient to keep fine particles in a constant state of progression towards the 8 inch blow-off at Burrard Inlet. However, should an accumulation of silt from some unexpected cause take place at any of these bends, the deposit may readily and with reasonable expense be removed by the ordinary means adopted in such cases, such as self-acting scrapers, spring gouges, etc.

Mr. Summerfield unhesitatingly states that it is very evident, from the description given of the turning on of the water, that "water ram and air compression were treated as a myth." This is, to say the least, a hasty and ill-considered assertion, in no wise warranted by the account given. It is evident that, in this instance, he has pictured to himself a system of water works, being opened for the first time with a full velocity of water flowing, and every air-valve and blow-off closed. This portion of the paper was necessarily brief, and did not contain details minute enough to give a full and complete description of how the work was accomplished. Moreover, Mr. Summerfield, although he makes no mention of the fact, may have been led somewhat astray by a clerical error which appears to have crept into the manuscript or print. In the latter it is stated—"at 9.45 p.m. the water reached the closed 12 inch valves on the north shore of Burrard Inlet." For "valves" should be read valve. If this faulty paragraph had anything to do with the misunderstanding

which seems to have occurred, it is to be regretted. But, in any case, in order that a clear conception be obtained of the manner in which the mains were first filled, the following more minute description is given.

When it was decided to make a test trial of the line of mains, the gate at the well chambers of the dam was lifted high enough to expose a segment of the 22 inch main 3 inches deep; the 8 inch blow-off at the tunnel and all the air-valves being wide open. By means of these, the air was expelled, the incoming water occupying its place, and very gradually filling up the main until it was discharging freely through the blow-off. The 22 inch main was allowed to continue in this state for a period of 48 hours. No breakage or sign of leakage having taken place, the gate at the well chambers was lifted from time to time, until, on the 5th day from the first partial opening, it was opened wide, the water in the main discharging freely through the 8 inch blow-off.

This trial being so satisfactory, it was then decided to test the 16 inch main. The 8 inch blow-off, before mentioned, was partially closed, and the water allowed to rise up the steep incline to the tunnel, until that part of the 22 inch main passing through the tunnel, and connecting with the 16 inch main, was filled one quarter full. How very slowly this was accomplished will be understood from the fact that, although the 22 inch main was nearly full up to the 8 inch blow-off, it required two hours from the time of partially closing that blow-off to reach the floor of the tunnel. The 22 inch main was not allowed to exceed about one-quarter full, but was maintained at this level, slowly and uniformly filling up the 16 inch main, until it was discharging freely by means of one of its 12 inch valves and the 8 inch blow-off at Burrard Inlet, the other 12 inch valve being kept closed in order to prevent the water entering the 12 inch main under the narrows. As in the case of the 22 inch main, all air-valves were kept wide open, allowing free vent for the escape of air, and affording absolutely no opportunity for air compression or hydraulic ram.

It is much to be regretted that Mr. Summerfield cannot be gratified in his desire for information as to the behaviour of the 16 inch main, under such (very contradictory) conditions as "*a full head of* water flowing with a velocity of 1.4 feet per second." As Mr. Summerfield calculated the velocity with which the water in this main travelled during the test trial, using the time and distance given in the paper, it is somewhat surprising that he did not also calculate the velocity due to the head and length, and thus avoid the error into which he appears to have fallen. From the data at his disposal, he might

readily have deduced, that, under a full head of water, the velocity of discharge at the termination of the main in the city is $5\frac{8}{10}$ feet per second. But, as the portion referred to in the present instance is only that between the tunnel and Burrard Inlet, if a full head of water had been allowed to enter the 16 inch main at the tunnel, the velocity of out-flow would have been found to greatly exceed $5\frac{8}{10}$ feet per second, using as data the total fall 388 feet, and total length 19,320 feet, between these two points.

Had Mr. Summerfield ascertained these facts, he could not have fallen into the rather extraordinary belief that water ram and air compression had been treated as a myth; and it may be here mentioned, that, had both 12 inch valves been closed, and only the air-valves along the line and the 8 inch blow-off at Burrard Inlet been open, these latter would have been amply sufficient for the discharge of air and the prevention of hydraulic ram.

The day following the turning on of the water, a thorough examination of the whole line of mains from Burrard Inlet to the dam was made. Throughout the whole distance, no sign of leakage was apparent. Mr. Summerfield's inferences that "something occurred" are without foundation.

The reducing tank referred to is entirely temporary, having been built solely to relieve the pressure on certain defective pipe lengths in the lower levels of the system, until new lengths could be manufactured and substituted.

With reference to the remarks of Mr. Russell Duncan, in a comparison between steel pipes jointed by the Moore and Smith joint, and those jointed by means of faucets and spigots attached to the shell, the word "cumbersome" was used in reference to the latter. This was a general expression, and not intended to particularize any individual joint, such as the Riley patent referred to by Mr. Duncan, and it may have been used without due consideration.

It is merely a matter of opinion, which is the simpler joint of the two; but on comparing them, it certainly seems that a joint consisting of a plain nipple and ring is simpler and more easily handled than a joint made in imitation of ordinary cast-iron joints.

Without details of the particular joint referred to by Mr. Duncan, it cannot be determined whether it requires a less quantity of lead, as he avers, than the Moore and Smith joint; but it is open to question, whether any safe spigot and faucet joint can be designed for 16 inch or 22 inch pipes, which will require less lead than $27\frac{3}{10}$ lbs. and $37\frac{4}{100}$ lbs., respectively, the amounts used in the Vancouver water works for

these diameters. In the pamphlet issued by the London Steel Pipe Company, it is claimed that the steel spigot and faucet joint of a 24 inch pipe requires 9½ per cent. less lead than the joint of a cast-iron pipe of the same diameter. (See author's paper, page 337.)

According to American practice, a cast-iron joint for a 24 inch pipe would require not less than 50 lbs. of lead; consequently, Mr. Duncan's joint for the same diameter would require 50 lbs. less 9½ per cent., or 45¼ lbs. But it can be easily calculated that a Moore and Smith joint for a 24 inch steel main $\frac{11}{100}$ of an inch thick with $\frac{5}{16}$ inch thickness of lead, the usual allowance, would require only 39¼ lbs. It appears, therefore, that in the case of a 24 inch pipe, according to the London Steel Pipe Company's pamphlet, as applied to American practice, the Moore and Smith joint requires 5¾ lbs. less lead than the spigot and faucet joint recommended by them.

As for great flexibility at the joints, it is not advisable in any system of water works to make with large mains much angular deviation, without special castings. It is not necessary, however, with the Moore and Smith joint to lay the pipes in a perfectly straight line, as claimed by Mr. Duncan, contrary to the description given. It will, on occasion, admit of deflection to the extent of one degree per length. In the case of 24 feet lengths, this would form an 8 degree curve of 716 feet radius. Without actual knowledge of such curves having been put in practice, it would be unwise to express an opinion as to their suitability; but there can be no question, that by means of this joint, such a curve as that on the Tay Viaduct, alluded to by Mr. Duncan, round which his 9 inch spigot and faucet pipe was laid, can be easily overcome, it being only a 4° 10′ curve with a radius of 1386 feet.

The nipple of the Moore and Smith joint in the Vancouver Water Works pipes does not decrease the internal diameter of the pipes at the joints; but in thickness of pipe shell over $\frac{11}{100}$ of an inch actually increases it. Had careful consideration been given to the drawing (Plate XX), there could have been no misconception on this point. It is there plainly shown, that the end courses of each pipe length are large or outer courses. The nipple being inserted in the end of a large course must, therefore, when of the same thickness as the shell, have the same inside diameter as the inner or small course, which, it is unnecessary to state, is the governing diameter of the pipe. The nipple adds greatly to the stiffness of the shell at the joint, but having no water pressure to withstand is, for economy sake, usually made of thin material, so that, in the case of a thick pipe shell, the inside diameter at the joint is greater than the governing diameter.

The reply given to Mr. Summerfield fully answers Mr. Duncan's doubts as to the strength of the 16 and 22 inch mains in comparison with ordinary Californian practice. When he reviews this subject, it would be well to bear in mind that there is no equality of strength between wrought iron and steel.

The omission of mention of the test pressures imposed on the mains was an oversight. The engineer's specification, and the company's agreement with the contractors for supplying and laying the steel mains, provided that the pipes should withstand safely and without leakage a column of water 600 feet high or 260 lbs. pressure to the square inch; and in order to insure the application of proof tests by the contractors, a special clause bound them to maintain and keep the whole system perfectly tight for two months after completion. So far as the engineers are concerned, these are the terms of the contract to this day. It will be admitted that no more stringent agreement for the laying of properly tested pipes could have been entered into.

Full details of the rivetting of the 12 inch, 16 inch, and 22 inch mains in the form of a table headed, "Details of Rivetted Steel Mains," accompanied the paper under discussion, when forwarded to the Society. That this table did not appear in the advance proof is to be regretted. However, it has now been embodied in the appendix to the paper, Vol. III., page 361.

Mr. Duncan's inferences and quotations from the author's letter to him are liable to mislead.

Immediately after the successful turning on of the water, the concluding portion of the paper, in which the account appears, was written, and the whole forwarded to the Society. There is nothing in this account at variance with the facts contained in the letter of April 13th. The primary leaks which were discovered up to the time of forwarding the paper to the Society were being readily repaired in the manner described. But, on the second day after the main had been put under *full pressure*, leaks developed themselves in the low-lying parts of the system, of an altogether different nature, and too numerous to be economically repaired in the same manner. The extracts quoted by Mr. Duncan were not intended by the author to reflect in any way on the character of the mains, as would be plainly seen were the latter given in full. The information afforded him was to serve as data on which to answer the questions, whether in his experience he had ever known a jet of water forced out between the laps of a rivetted pipe to actually cut the shell of the pipe beyond the laps, and, if so, what remedies were adopted by him? This was what had occurred in the Vancouver system, after the paper had left the author's possession.

Mr. Duncan in his reply could state no similar case; but very kindly advanced many theories, among which were the following:— "That an hydraulic ram had occurred; that the rivetting of the seams was faulty; that the plates were not laid flat together at the seams; that there may have been burrs left at the rivet holes; that in caulking, the edge of the plate may have been upset so as to spring one plate more than another; and that the rivets may have been pitched too far apart." Any one of these causes would have been sufficient reason for leakage between the laps, but would not account for the cutting of the steel plates beyond the laps, which was the point upon which information was desired. The most probable explanation of this phenomenon, of a water jet apparently cutting steel, is that, in rivetting the plates together, too much power was used, the effect being to compress the plates at the rivets, and to buckle them in the intervals between, thus allowing the water when under full pressure to be forced out with great velocity. As the soil in which the injured pipe lengths are laid is nearly pure sand, the sand particles mixed with the escaping jets, and being kept in constant motion, acted as sand blasts at the points where the jets struck the shell just beyond the laps. This theory is supported by the fact, that the pipe shells were not cut where the excavations were in earth or clay, and that part of the 12 inch steel main which was uncovered, though leaking at several laps, showed no sign of abrasion. It has since been learned that similar occurrences have taken place in eastern cities, where the practice is, either to box the mains, or remove the sand and substitute clay.

Answers to the queries proposed by Mr. Duncan as to rivetting, coating, etc., etc., are to be found in the paper.

With reference to the statement that the pipe lengths being 23′ 9¾″, four courses would have been preferable to seven in the manufacture of each length, it may be briefly replied, that four courses would not have answered in the kind of pipe used. In order to admit of a nipple which would not lessen the governing diameter of the main, it was necessary that a large or outer course should be at each end of each length. This could only be (see Plate XX.) when each length consisted of 2, 5, or 7 courses. The "preferable pipe" of 4 courses would have had a small course at one end, which would not have received a nipple, except of less diameter than itself. If a nipple were dispensed with, and the smaller course forced into the larger, this latter, overlapping the other, would make the thickness of lead, at each side of the junction, unequal.

As to its being bad practice to make up each pipe length of 7 courses of so-called small plates, this is a matter of opinion, and not warranted

by custom on the Pacific Coast. The pipes of the Vancouver system have been endorsed by the best authority in California, and as a notable example of similar design, the 36 inch wrought iron main of the Spring Valley Water Works, Cal., may be cited. The specification of this pipe calls for plates 116″ × 44″.

It is a questionable statement, and unsupported by proof, to say that caulking the seams as described tends to aggravate leaks. Experience on this coast has shown that, to obtain perfectly tight seams, chipping, caulking and split caulking are necessary. A reference to the specification of the Spring Valley Water Works, California, and the Portland Water Works, Oregon, will give further information on this point.

The spigot and faucet joint, having only one surface to be caulked, requires less labour in laying than the Moore and Smith joint, which, owing to its simple construction, has two surfaces. This advantage, however, is more than counterbalanced by the original labour of making the spigots and faucets, and attaching them to the shell. Had the cost of these details been given, a satisfactory comparison could have been made, which might not have been unfavorable to the Moore and Smith joint.

The statement made, that in the Riley patent socket joint it is not found that the shell is bent inward by caulking, as is the case with the Moore and Smith joint described in the paper, is misleading. The paper merely says: "That if the lead is beaten between the ring and the pipe too tightly, the shell of the latter will bend inward; and that it is necessary to caution inexperienced caulkers with regard to this." But in the hands of caulkers who have learned their business, the Moore and Smith joint is as free from liability to defective workmanship as any other joint; an assertion which is amply proved by the fact that in the Vancouver Water Works system, after the pipes had been subjected to a full pressure for several weeks, no joint in the whole length of 10 miles was found to leak.

Mr. Duncan claims that owing to the spigot end of the socket joint pipe being made 50 per cent. thicker than the shell, no pressure imposed in caulking will indent it. This is somewhat strange, seeing that he admits the possibility of the shell of the Moore and Smith joint pipe being bent, where the extra thickness exposed to the pressure of caulking is often, as in the case of the Vancouver mains, 100 per cent. In the latter joint, a nipple or ring 5 inches wide, and of the same thickness as the pipe shell, is closely fitted to the interior surface of the pipe, directly under the 4 inch ring of lead to be caulked, thus doubling the thickness of metal exposed to the pressure of caulking.

Mr. Duncan's concluding observations afford very valuable information as to the manufacture of pipes by the London Steel Pipe Company. When in London some months ago the author had the pleasure of seeing various specimens of these pipes, and was much struck by their excellence. For finish and workmanship, they are not likely to be surpassed; and it is very desirable that full information regarding them should be well known.

In reply to Mr. Henshaw, as to the question of an anchor falling on the submerged main, it is conceded that it would be undesirable to invite a trial; but in the event of such a test being made, it is by no means certain that the disastrous effects hinted at would take place. In any case, such an occurrence is a very remote possibility, even with one submerged main; while, that an accident should happen to two at the same time is almost an impossibility.

With reference to the remarks of Messrs. Blackwell, Smith, Goad, Peterson, Gower and Bovey, there is no mistake about the dimensions of the Cedar in question. Should Messrs. Blackwell, Smith and Goad care to visit British Columbia, they can have the pleasure of verifying the measurements. The Cedar is dead, but is very uniform from the ground upwards, and has no abnormal enlargement at the base. Such trees are rarely solid, and this is no exception. In trenching for pipe lines, it is not usual to extract such stumps, it being much more economical to tunnel under them.

A working plan of the dam, drawn to the scale of 8 feet to the inch, accompanied the paper on the Vancouver Water Works. It was considered that this would, if hung on the wall, have afforded all necessary information.

As the whole front of the dam is protected by double sheet piling, overlapping, with the ends imbedded in a trench of concrete sunk in the bottom of the river, and the shore connections protected on the south side by a hand-laid stone wall with a well rammed gravel and earth backing, and on the north side by a gravel embankment of picked material, the chance of water percolation through the body of the dam, and seepage round the ends, has been reduced to a minimum. Certainly, none has taken place during the two years of the dam's existence. The trench in which the sheet piling is imbedded, owing to the shallowness of the river, was filled with concrete in a simple manner. The concrete was wheeled over gangways extending along the face of the dam, within a few inches of the water, was then deposited over the sides, and allowed to settle in the trench. Twenty-four hours after the trench had been filled, the concrete was firm enough to resist moderate probing.

The definite object in view in the manufacture of the concrete was imperviousness and a thoroughly secure connection between the foundations of the dam and the bed of the river. The space in which it was to be placed was very confined, being a narrow trench, not exceeding at any point a depth of 3 feet; and being for the most part entirely under water, it would not permit of the filling being packed and rammed. These objects could only be obtained by making the concrete of such small materials that the whole would form as nearly as possible a homogeneous mass.

The author's experience in the manufacture of concrete is not extensive enough to permit of his expressing an opinion as to the advisability of employing large stones. But it is worthy of note, that the specifications for the water works systems of Gosport, Lambeth, Bideford, Halifax, and Aberdeen distinctly require that either sharp gravel be employed, or that all stones shall be broken so as to pass through a ring 1½ or 2 inches diameter. Also, Trautwine (page 680, edition 1886) states "that broken stone for concrete is generally specified not to exceed about 2 inches on any side; but if well freed from dust, all sizes from ½ inch to 4 inches on any side may be used."

It is therefore apparent that if eminent authorities advocate the use of large stones, many quite as eminent do not.

The Teredo Navalis, not being gifted by nature with the acrobatic powers of the salmon, is not likely to ever find a home in the timbers of the dam.

Corrosion of metal exposed to the action of salt water is a subject of great importance; and it is a matter for surprise that really reliable information with regard to it is difficult to obtain. But experience, so far, goes to prove that steel and wrought or cast iron of proper quality resist this action for long periods. Trautwine says "that certain cast iron sea piles of hard white metal showed no deterioration after 40 years immersion." (page 218, edition 1886.) The double 8 inch cast-iron pipes laid across Shirley gut nearly 20 years ago are in active operation to this day. In the discussion on the Avon Bridge, published in the last volume of the Society's Transactions, Mr. Uniacke in reply to Mr. Blackwell (page 286) says: "That bolts and plates used in the construction of the old bridge, 50 years ago, and exposed to salt water at different stages of the tide, showed not the slightest corrosion." Also, in constructing the new steel dock gates of Limerick Floating Dock, the pintles of the old gates were found to be so little affected by their 38 years' exposure to salt water, that they were used again.

It is to be noted that the cast-iron in the Vancouver submerged main is of the quality approved of in Trautwine; and, also, that there are many instances of similar mains submerged in salt water, designed by eminent engineers; as, for example, the aforementioned Shirley gut pipes, the Bournemouth storm outfall, the San Francisco Bay mains and the San Diego Bay main. Full information as to the manufacture, specification, quality, and proof tests of the submerged main are given in the paper on pages 344, 348, 351.

It is difficult to believe that Mr. Peterson's remarks relating to his observations when in Vancouver are uttered in any other than a jocular spirit. No one can suppose that because an irresponsible individual volunteered the information that the steel mains (wrought iron, he calls them) were not sufficiently strong to withstand the pressure, he credited that statement without investigation. It is hard to understand his imagining the rivets to be 4 or 5 inches apart, seeing that this is nearly 4 times the extreme distance. The round seam rivets of the 12 inch and 16 inch mains, referred to by him, are 1.2 inches and 1.08 inches apart, from centre to centre, respectively; and the straight seam rivets, which are in double rows, 1.3 inches and 1.4 inches. It is impossible he can believe that any steel or wrought iron pipe, which had so yielded to pressure that water was flowing in little streams out of nearly all the joints of the sides, could be held together and rendered serviceable by straps placed round it. All new rivetted pipes weep more or less at the laps, when first put under pressure. The great majority of the leaks he observed, being on the south side of the Inlet, where there was little or no sand to cut the plates, "took up" of their own accord, without special repairs.

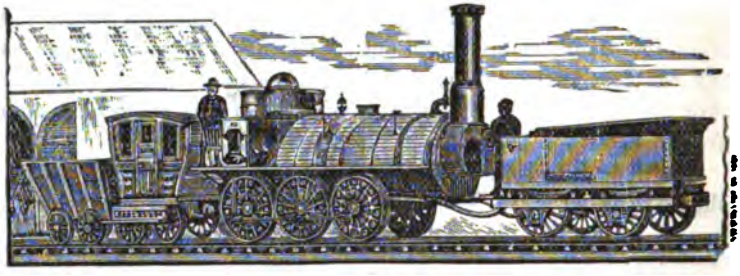
The submains are 8 inches, 6 inches, and 4 inches in diameter; not 4 inches and 2½ inches. 2½ inch welded wrought iron tubes have been laid for short distances, as a temporary means of supply for certain buildings. No hydrants are connected with 2½ inch pipes.

The distribution system was designed by the most eminent authority on water works in Canada, Mr. T. C. Keefer, C.E., C.M.G.

In the case of Vancouver, there is a very substantial reason why the water works should be in the hands of a private company. They were projected before the city had an existence, and constructed at a time when the city's resources were being fully employed in making absolutely necessary improvements, and it is doubtful whether even at this day the city would care to incur the expense of water works construction.

Thursday, 16th January.

K. W. BLACKWELL, Member of Council, in the chair.



THE SAMSON.

Paper No. 36.

ONE OF THE OLDEST RAIL ROADS IN CANADA.

By H. S. Poole, M. Can. Soc. C. E.

In 1818, when coal mines were first opened on the East River of Pictou, a tram road was made from the pits to the head of the tide, above where the iron railway bridge now spans the river; but shipments were small until a transfer of the property took place in 1827, when a new site for the wharves was selected lower down the river.

As the trade grew and the inconvenience of shipping in shallow waters was more and more felt, other sites still lower down were found, and so it came about that in the course of ten years four moves were made.

The tram road was of the now standard gauge, 4′ 8½″, and was worked by horses. Sidings were placed about half a mile apart, and each horse went his half mile or so with a full load, and, leaving it on the main line for the next horse to take on, returned with empty wagons from the siding.

When, in 1834, it was found that much improved facilities were required to meet the growing trade, the final site was selected opposite the loading ground, some four or five miles further down the river from the shipping place in use, at a point where there was ample water for vessels of the largest size then engaged in the coal trade.

The extension then decided on was subsequently built in a more substantial manner than the upper part of the road had been made. It was finished in 1838, and in that year the first locomotive ran over a rail road in Nova Scotia.

For half a century this rail road was in operation, and for many years carried passengers as well as freight; it was finally abandoned last autumn, and the shipping of coal transferred from the loading ground where this South Pictou Rail Road terminated, to wharves at the mouth of the harbour, access to which is obtained over a branch of the Intercolonial Railway to Pictou Landing. These newer wharves will accommodate any vessel that can cross the bar at the harbour's mouth, they are accessible earlier and later in the season than those at the loading ground, and from them loaded vessels can sail at any time of the tide day or night.

When the tram road gave place to the rail road, the line to the pits was also changed, and the whole length of seven miles came under new surveys.

The President of this Society has spoken of the desirability of recording the names of those who were pioneers in the several branches of the profession of engineering, and the writer would now name Mr. Peter Crerar as one of the earliest railroad engineers in Nova Scotia, if not in Canada.

Mr. Crerar was born in 1785 at Breadalbane in Perthshire, and came to Nova Scotia in 1817. He first taught in a school and then became deputy land surveyor, in which latter capacity he laid out several of what are now the main roads in Pictou County. He died in 1857.

Mr. Crerar* had had no experience in railroad surveying and building prior to the time when he was engaged to run the trial lines of the extension of the South Pictou Rail Road; yet when his plans and specifications were laid before the Board of Directors "at home," they were so well satisfied with them that they wrote out, saying: "What need is there of our sending you an engineer when you have Mr. Crerar in the country? Let him supervise the construction." This was accordingly done, and several of the sections he prepared to show the progress of the work have been preserved. One of these sections the writer is, by the kindness of Mr. Clendenin, the President of the Acadia Coal Company, the present owners of the property, enabled herewith to send for preservation in the archives of the Society. (See Plates I to III.)

A glance at Mr. Crerar's section is arrested by the unusual uniformity of the grade for a road passing through a country so uneven as there shown, so different from that ordinarily met with on colliery railways built in the present day. The road starts from the pits with a falling grade of one in 437 feet for a distance of 3500 feet, thence it is practically level for 18,770 feet, a slight incline of one in 578 feet then follows

* In some papers he signs himself "Geographic Engineer."

for 2,500 feet, succeeded by a level piece of road for 5,810 feet; a grade of one in 360 feet for 1,500 feet then takes the road to the timber structure, in connection with the wharf 16½ feet above ordinary high tide.

It will also be noticed on the plan of the road that in the matter of curves great caution has been shown; as, even when it entailed extra cutting of considerable amount, nowhere is there a curve of over 4 degrees radius.

The cuttings and embankments were both made with a slope of one and a half to one; the former being made 18 feet wide at the bottom, and the latter of the same width at the top.

Among the papers relating to the construction of the road is the following memorandum, connected with the first line in England intended for general traffic :—

"The Liverpool and Manchester Rail Road.

"Iron Rail Road account £67,912.0.0.

"The above expenditure comprises the following items : Rail for a double way from Liverpool to Manchester, with occasional lines of communication and additional side lines at the different depots, being about 35 miles of double way = 3,847 tons, at prices averaging something less than £12.10.0. per ton."

In addition to the interest which this memorandum has as a statement of cost, the author would specially draw attention to the use in it of the words "depot" and "rail road." Their use here makes it probable that these words were common in England at the time in question, although they have been there abandoned and replaced by "station" and "railway."

It would appear probable that these terms were at the same time adopted in America, but, in contradistinction to the English practice, they were retained there just as philologists tell us many words and expressions, which are distinctive of New England to-day, are recollections of Puritan times, and are not indigenous to the soil. Only the other day, a reviewer, writing on the great American language, gave "depot" as an adaptation from the French direct by the people of America; but it would seem that the use of that word in the foregoing memorandum points to its having had at least a temporary resting place in England on its way to America.

It may be noted that in all the papers connected with the South Pictou road the invariable practice is to speak of it as a "rail road," never as a "railroad" or "railway," and this spelling the writer has retained in this paper.

The road has, as already mentioned, a gauge of 4′ 8½″, as was the practice in England at the time of its building. The rails were of several sections, of which pieces have been sent to the Museum of the Society. The earliest form was scalloped to sit in metal chairs spiked to sleepers placed 3 feet apart. The turnouts are made with tongues or split points of the form now required by the British Board of Trade, and one which has of late grown more in favour in America than the facing points ordinarily seen.

Locomotives:—The first engine to run on the road was the Samson, which is still in working order, and was in use until 1884. This engine led in the procession of locomotives at the Chicago exhibition in 1883, and was driven by George Davidson, who came out with it from England in 1838.

The John Buddle and the Hercules were imported at the same time, and were similarly constructed; they were followed by the Albion and Pictou, which have inclined cylinders and tubular boilers, and subsequently in 1853 by the Vulcan, which has the cylinders placed horizontally.

The boiler of the John Buddle is now used to drive a stationary engine, and the others are not beyond repair if use could be found for them. The veteran Samson is waiting for a purchaser* who will preserve it as a relic of past practice. It was built by Timothy Hackworth of Newcastle, weighs 16 tons, 19 cwt., 0 gr., 20 lbs., and with duplicate wheels and other parts cost £2140 cy.

The cylinders are 15½″ diameter, with a stroke of 16″ and a valve area of 2½ sq. ins. They sit vertically over the hind driving wheels, and have Watt's parallel motion instead of crossheads and slides. The wheels are 4′ in diameter, six in number, with a wheel base of 8′ 8″; they are made in two pieces, the annular portion is kept in position round the central hub by twelve circular keys of wood.

The boiler with a capacity of 540 gallons is 54″ in diameter, has a length of 13′ 4″, and carried a pressure of 60 lbs. on the square inch. It has a single return flue of ⅜″ plate, single rivetted, 26½″ in diameter round the fire, and diminishing to 18″ where it enters the smoke box. Another novelty lies in the exhaust pipe passing from the cylinders through the shell to the smoke stack. As constructed the tender goes behind, and the stoker alone attends to the firing, while the driver sits in an iron chair in front of his engine, and has an uninterrupted view along the line.

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* Price asked $500

The writer, among the notes of his father, who managed the Albion Mines for the General Mining Association for fourteen years, finds a careful record of the work done by each locomotive; and between the years 1840 and 1853, the Samson on an average in each year was out 113 days, ran 4721 miles a year, and hauled 21,913 chaldrons of coal, at an average annual cost of £61 9s. 6d. cy.* for repairs, and £227 13s. 2d. cy. for working expenses.

Cost of material and work.—The writer has come across a few items of cost with which material and work of to-day may be compared, *e. g.*, The actual cost of earth cuttings per yard ranged from tenpence to one shilling and threepence, 62,297 yards costing £3247 7s. 5d. In later work the rate paid was even lower, and down to 5¾d. per cubic yard for levelling a coal floor. At the present time, cuttings through the same class of ground, stiff boulder clay with embedded rocks and pebbles, could not be made under thirty cents per cubic yard.

Spruce 1½″ and 2″ boards were bought for 22 shillings per thousand; hemlock at nineteen and six pence.

Hemlock logs not less than 15″ diameter as follows:—

27	logs	36	feet	long	each at	4s. 6d.
297	"	25	"	"	"	3s.
54	"	24	"	"	"	2s. 10d.
567	"	19	"	"	"	2s. 5d.
1356	"	13	"	"	"	1s. 9d. in all £233 0s. 9d.

Cedar sleepers from New Brunswick were delivered at 2s. each in 1846, and at from 1s. 9d. to 2s. 6d. in 1847.

Iron rails, 21,149 yards, weighed 617 tons 14 cwt., and required 258 tons 2 cwt. of metal chairs and 35 tons 17 cwt. of pins and wedges.

As an example of stone work take the cost in 1850 of a culvert 4 feet in diameter, 143 feet long, under an embankment 35 feet high.

Finding and hauling stone 9 miles at..... 10s. 6d. per c. yd.
Building same..... 4s. " "
Face dressing inside of culvert and including reducing the stone to the mould of the arch 18″ thick, stones 7″ at face, 11″ at back at..... 12s. 6d. " "

Then a retaining wall 90 feet long by 24 feet high, 7 feet thick at the bottom, and 4 feet 3 inches wide at the top, was built, the stone found and the face chisel dressed for 12s. 6d. per cubic yard.

The writer has not been able to make out the actual first cost of the road, but in after years the valuation, inclusive of land damages and engines, stood at £76,700 1s. 0d.

* The £1 cy. was worth 16s. stg.

The following, however, is the estimate by Mr. Crerar of the probable expense of completing the Albion Mines Rail Road, from its commencement at the foundry to its termination at the Loading ground :—

	Currency.
Excavating 135,980 cubic yards @ 1s. 2½d.	£8,882 2 6
21,600 tons prepared stones laid on @ 6s. 6d. per ton	7,020 0 0
10,560 sleepers @ 1s. 3d. each	660 0 0
Laying down same and rails, etc	660 0 0
A bridge at Simon Fraser's Cove, stone abutments, each averaging 30 ft. high, wooden tops supported by wooden piers or pier poles, etc., etc.	447 0 0
A bridge across Cove Brook, etc., etc	579 0 0
A bridge from Dunbar's Point to Loading ground, one stone abutment, etc	1593 0 0
15 bridges and passing places, stone abutments, wooden tops, averaging 20 ft. high and 15 ft. span, at £180 each	2,700 0 0
Drains and culverts	800 0 0
600 tons iron rails, chairs, etc., @ £15 per ton	9,000 0 0
	32,341 2 6
Ten per cent. contingencies	3,234 2 3
	£35,575 4 9

Having located the line, the next step was to obtain the right of way, and as in those days there was no Railway Act, it may be of interest to note what proceedings were actually taken.

First, application was made to the General Sessions of the county, and then, in accordance with the authority there obtained, there was issued the following notice and in due course the Jury's award :—

NOTICE is hereby given that pursuant to an order of the Justices of the General Sessions of the Peace for the County of Pictou, dated the 4th day of January instant, made upon the application of the General Mining Association, which Association are the sublessees of His Majesty's mines in the Province of Nova Scotia, by Joseph Smith, Esquire, their agent and attorney, a precept in writing has been issued, directed to the Sheriff of the county of Pictou, or his deputy, commanding him to summon certain persons being freeholders to appear at the house of James Fraser, innkeeper, in the town of New Glasgow, on Tuesday, the 4th day of April next ensuing, at 11 o'clock forenoon, for the purpose

of laying out and setting off within the lands of any person or persons owning the same, or in possession thereof, so much of the said land as may be required for the purpose of altering the line of rail road, now in use at the Albion Mines on the East River of Pictou, in the county aforesaid, the whole way from the shafts or pits at the said mines, down the west side of the said river to some convenient point opposite to what is generally called the "Loading Ground," and for assessing the damages to the owner or owners, tenant or tenants of such lands, according to their several interests, for being deprived of the use and benefit thereof; and for the expense of making fences or ditches, and also for fixing and ascertaining the annual rents for the use and occupation of the said lands, in accordance with the laws of the Province in such case made and provided.

(Signed,) JAS. MINNESTER,
Clerk of the Sessions.

Pictou, January 6th, 1837.

At the house of James Fraser, Innkeeper, in the Town of New Glasgow, this sixth day of May, one thousand eight hundred and thirty-four.

A list or panel of the names of twelve of the freeholders summoned and in attendance, under and by virtue of the precept hereto annexed, who on the list of freeholders to the said precept annexed being called over first appeared and answered thereon, and who were thereupon sworn by me the subscriber, John W. Harris, the deputy of John J. Sawyer, Esquire, sheriff of the County of Halifax, as a jury to the faithful discharge of the duties required of them by the laws of the Province, touching the several matters and things in the said precept mentioned and set forth namely:—(Alexander McDonald and others.)

VERDICT OR FINDING OF THE ABOVE JURY.

We whose names are hereto subscribed, being the jurors named in the above list or panel, do hereby certify, that being first duly sworn we proceeded to the discharge of the duties imposed on us, and having traversed the line proposed by the agents of the trustees of the General Mining Association, as an extension of the rail road from the shafts or pits at the Albion Mines on the East River of Pictou, the whole way from the said shafts or pits down the west side of said river, to a point in said river opposite to what is called the loading ground, as shown to us by the said agents of said trustees, and having heard all such parties interested therein, as well for as against their several proofs, opinions,

plans, estimates and suggestions as appeared before us, and having again by ourselves, separate and apart from all interested therein, given the whole business referred to us our most mature deliberation, do say that in our judgment it is needful and requisite to extend the said line of rail road the whole way from the said shafts or pits, to a point or place in the said East River of Pictou, opposite to the said loading ground, that being the nearest sea water navigable for loaded ships or vessels of any size in the said river; and that for the purpose of so extending the said rail road, it is needful and necessary to open and make the same across and in front of the lands lying on the west side of the said river, between the said shafts or pits and the said loading ground, on the several courses as shown upon the plans hereunto annexed, which plans are made and signed by Peter Crerar, deputy land surveyor and civil engineer, and thereupon for that purpose we do hereby lay out and make as the same is now marked and staked on the ground, and shown upon the said plan, through, over and within the lands following, that is to say, commencing at or near the foundry, that being a short distance from the said shafts and pits, and to which place the said rail road has been previously laid down and established as we are informed, and running from thence through, over, and within the lands now in the possession of the said General Mining Association, one John Duff, one William Fraser "Ogg," one William Blair, the widow and heirs of the late Donald Smith deceased, and then again of the said Association to the bridge at New Glasgow, and passing under the western end of the said bridge, thence to run through, over and within the lands of the said Association, one Donald Fraser, mason, one Thomas Fraser, one Edmund Walter Remdell, one Donald McKenzie, one William McIntosh, Messrs. Simon James and John Fraser, again other land of the said Association; Messrs. George and John Fraser, one William McRay, again more land of the said Association; one Alexander McDonald, one Donald Fraser, the widow and heirs of the late Colin Fraser deceased, and Messrs. Robert and William Dunbar, and from the said Robert and William Dunbar's lands into the said East River, to a point opposite the said loading ground, according to the said plan, allowing for the purpose of opening and making the said rail road so much of the land on each side of the said line not exceeding more than five nor in any case less than three rods in the whole breadth thereof, clear of fences and ditches, except at such places as the said line shall or may pass into or out of the waters of the said river, as may be requisite and necessary for the formation of a proper rail road, when so extended as aforesaid, and we have assessed the damages to be paid by the said trustees of the said Association to

the owner or owners, tenant or tenants of the said lands, according to their several interests therein, or to such other person or persons as may be lawfully entitled to receive the same, for being deprived of the use and benefit of such land, and for the injury that may be done thereto, and for the expense which may be imposed on them for making fences or ditches, for the purpose of separating all the lands so laid off as aforesaid from other parts of the tracts of land, within which the lands so laid off are contained as follows: that is to say, for damages and fencing on and over the land now in the possession of the said Robert and William Dunbar, seventy-three pounds ten shillings, and for the like, etc., etc., all which said sums are to be lawful money of Nova Scotia, and to be paid to the person or persons entitled thereto as aforesaid by the said trustees of the said Association, when and so soon as the said line of railroad is commenced and the fences put up in a lawful manner.

And we have also fixed and ascertained the annual rent for the use and occupation of the said lands, laid off as aforesaid as follows, that is to say, for so much thereof clear of any fences or ditches as shall be requisite and necessary for the purpose of the said rail road, when so extended as aforesaid, the same to be ascertained by actual measurement by a sworn deputy surveyor of land when the said rail road is formed, which is now in possession of the said Robert and William Dunbar, etc., etc., the annual rent of four pounds for each and every acre and so in proportion for any lesser quantity that may be requisite, etc. (N.B.—Other lots are at two pounds, two pounds ten shillings, three pounds, five pounds), which said sums hereby fixed for rent, being also of like lawful money as aforesaid, and to be paid by the said trustees in twelve months from and after the time when the proceedings had or to be had under the said precept shall have been confirmed, and soon yearly and each year thereafter, so long as they continue to occupy the said rail road. Provided always that such owner or owners, tenant or tenants, or such other person or persons entitled to receive such annual rent as aforesaid, do and shall from time to time, and at all times hereafter, so long as the said line so laid off and marked as aforesaid shall be held and occupied as aforesaid, at his or their expense, cost and charges, repair and keep in repair all such fences as he, she, or they are bound to put up in manner aforesaid, and in default thereof the said Association shall be at liberty to repair and keep in repair all such fences, and retain out of the annual rent aforesaid the reasonable expense and cost of the same. * * * And we have further considered that there shall be made at the expense of the said Association, either across or under the said rail road, when the same is formed and completed, suitable and commodious places for the owner or owners,

tenant or tenants respectively of the several tracts of land through, over or within which the said line for the said rail road has been laid off and marked as aforesaid, to pass and repass from one part of the said tracts of land to the other, the said passing places to be in such part of the said line as will admit of their being made by a bridge at least fourteen feet above the level of the rails to be laid on the said road, or at such other part thereof as will admit of their being made to pass under the said line of rails, and to be at least ten feet clear, at the option of the owners, of the soil opposite thereto, and in case there shall not be on any of the said tracts of land an embankment of sufficient height or cutting of a sufficient depth, to admit of a passing place to be made as before described, then there shall be made as aforesaid one at such place on the said line, as there shall be neither a cutting nor embankment of more than three feet, such place to be pointed out by the owner opposite, and we further consider the number of said passing places shall be as follows, etc.

In witness we have hereto subscribed our names at the house of James Fraser, Innkeeper, at New Glasgow, this eighth day of May, one thousand eight hundred and thirty-four, having been three days engaged in this business, to us referred as aforesaid, in the presence of the said John W. Harris, who has subscribed his name hereto.

(Signed) Alex. McDonald.
his
George x Gratto.
mark
John Adamson.
Peter McLauchlan.
Joseph Trinniman.
his
James x Perrin.
mark
William Wylie.
Donald McGilveray.
Duncan McDougall.
John Lippincott.
Edward Patterson.
Jas. Purvis.
John W. Harris.
Depy. Sheriff.

From the drawing accompanying this paper Plates I, II and III have been prepared.

DISCUSSION.

Mr. Hannaford. Mr. Poole is mistaken in stating that the first locomotive in British North America ran on the Pictou Coal Mines tramway in 1838.

The first locomotive used on a railway in British North America was the "Dorchester" on the Champlain and St. Lawrence Railway, St. Johns, P. Q., to Laprairie, sent out in 1836, and operated regularly in 1837. This engine was built by George Stephenson & Co., Newcastle-on-Tyne, and was used for some years on the Liverpool and Manchester Railway before coming to Canada.

Mr. Blackwell. The speaker believes that the first locomotive in Canada ran on the old Champlain Road, and was called the "Dorchester." He remembers the matter being spoken of while serving his apprenticeship in the Grand Trunk shops 25 years ago. He did not know whether anyone remembered, but he thought that the conception, plans and carrying out of the old Champlain Road were all prior to the coal road in Nova Scotia now under discussion.

Mr. McNab. The Charter for the Champlain and St. Lawrence Railway was granted in February, 1832. The line was completed in 1834. In 1835 the locomotive "Dorchester" was brought out from England, as Mr. Hannaford said, and was running in 1836. The speaker understood that the Dorchester" was still in existence, driving a sawmill somewhere down East, having been sold several years ago for $300.00.

Mr. Macdougall The practice in Britain of distinguishing between "tramways" and "railways" is as carefully maintained at the present day, as the terms "tramway" and "railroad" were in the earlier days of the century.

Street railways are not known in Britain, they are specially designated street tramways.

The speaker can remember when the term "depot" was much more commonly used than "station," which is now the common term. The expression railroad was dropped in the early history of the movement. Many parliamentary plans he had seen of proposed lines early in the "forties" always have railway on the title of the bill.

Relative to the existence of the veteran "Sampson," he would mention a curious conjunction of the past and present. On the North

British Railway, the passenger, after stepping out of a train which travelled at sixty miles an hour for a considerable portion of the distance from Edinburgh to Carlisle, at Silloth Junction stepped into one of the original horse-coaches used on the first railroad from Edinburgh—the Edinburgh and Dalkeith—and was drawn by a horse for a distance of two miles.

Mr. Chadwick.

Mr. Poole's paper is one of great historical interest, and the writer regrets that he was unable to be present during the reading of the paper and the discussion which followed.

In the first edition of "Civil Engineering in North America," by David Stevenson, published in 1838, the author makes a short reference to the "Champlain and St. Lawrence Railway" as the only one in Canada at that date, stating that the line was 16 miles long, and was constructed of plate rails laid on wooden sleepers. Two locomotives, one built in England and the other in the United States, were used, but the names are not mentioned.

In the same work there is a description of what would appear to be the prototype of the "cow-catcher," but which was then called a "guard," and it is stated to have been first used on a short line, the Quincy Railway, Mass. It consisted of a sort of framing, attached to the front axle of the engine, from which it sloped to within an inch or two of the rails, upon which it ran, supported on a pair of small wheels five or six feet in front of the leading wheels of the locomotive. In the Transactions of the American Society of Mechanical Engineers, Vol. X., page 509, 1889, there is a paper by Mr. D. W. Robb, of Amherst, N.S., M. Am. Soc. M.E., on "The Old Locomotive Sampson." The paper is illustrated with drawings of this interesting old locomotive. The plan of carrying the exhaust pipe from the cylinder inside the shell of the boiler is very curious.

Thursday, 23rd January, 1890.

ANNUAL GENERAL MEETING.

COLONEL C. S. GZOWSKI, President, in the Chair.

MORNING SESSION.

The Secretary having read the notice convening the meeting, and also the minutes of the last annual meeting,

It was moved by Mr. John Kennedy, seconded by Mr. K. W. Blackwell, and resolved:—

"That the minutes as read be approved."

The following Annual Report was then read by the Secretary:

ANNUAL REPORT.

In resigning its charge at the expiry of another year, the Council has again much pleasure in reporting a year of progress.

ROLL OF THE SOCIETY.

During the past year the membership of the Society has steadily increased. The elections comprised *seven* honorary members, *fifteen* members, *eleven* associate members, *twenty-eight* associates, and *twenty-three* students, while from various causes *twenty-nine* have been removed from the list, the net increase for the year being *fifty-five*.

The total number on the list at the present date includes *seven* honorary members, *two hundred and sixty-five* members, *one hundred and two* associate members, *sixty-two* associates, and *one hundred and fifty-two* students, or *five hundred and eighty-eight* in all.

The resignations were:

Member—J. J. Collins,

Associate Member—H. Wilson.

Associates—John Taylor, N. N. Evans, G. M. Dawson.

Students—W. W. Baillairgé, W. S. Belcher, J. C. Burns, D. Cator, M. L. Hersey, T. R. Henderson.

The deceases have been:

Members—L. Lesage, E. E. Gilbert, C. B. Franks.

Student—W. H. Lough.

In this list will be observed the names of Mr. Louis Lesage and Mr. E. E. Gilbert. Mr. Lesage was an incorporator of the Society, and served on the two first councils. He was widely known, and

was one of the most respected engineers in the country. Mr. Gilbert was amongst the earliest of the mechanical engineers of Canada, and was the inventor of many valuable improvements. Only the other day, members of the Society heard of the death of our second President, the late Samuel Keefer, who might be considered one of the fathers of engineering in the Dominion. In him the Society has lost an ardent supporter and well-wisher. Still more recently we have received the sad news of the death of T. T. Vernon Smith, a pupil of Robert Stephenson's, and one of the last remaining links connecting our profession here with the early engineers of England. These losses will be severely felt, as the Society can ill afford to do without the advice and support of men of such long experience. Their memoirs will appear in due course in the Transactions.

The honorary members who have been elected are:—

His Excellency The Right Honourable LORD STANLEY OF PRESTON, G.C.B., P.C.

Sir John William Dawson, *Kt.*, C.M.G., LL.D., F.R.S.

Sir Charles Augustus Hartley, K.C.M.G., F.R.S.E.

Sir Frederick Joseph Bramwell, *Bart.*

Sir William Thomson, F.R.SS.L.&E., LL.D.

Sir John Fowler, *Bart.*

Sir John Hawkshaw, F.R.SS.L.&E.

The answers from the above accepting their elections are herewith appended:—

GOVERNMENT HOUSE,
OTTAWA, January 17th, 1889.

DEAR SIR,

Allow me, in acknowledging your letter, to ask you to be good enough to express to the President and Members of the Society of Civil Engineers my high appreciation of the compliment which they have paid me, by proposing that I shall be an Honorary Member, and my sense of the honour of belonging to such a distinguished body.

I remain, my dear Sir,
Yours very faithfully,
STANLEY OF PRESTON.

PROF. H. T. BOVEY, M.A.,
Sec. Can. Soc. C.E.

McGILL COLLEGE,
January 5th, 1889.

DEAR PROF. BOVEY,

Kindly convey to the Canadian Society of Civil Engineers my sincere thanks for the honour they have done me in my election as an Honorary Member, and

which I can assure you I very highly value. Any services that I can render to the Society are merely those of a worker in collateral and educational matters, but these I shall be always ready to render.

Sincerely yours,

J. WM. DAWSON.

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26 Pall Mall,
LONDON, 18th April, 1889.

DEAR SIR,

I beg to acknowledge the receipt of your letter of the 5th inst., informing me that, at an ordinary meeting of the Canadian Society of Civil Engineers, I was unanimously elected an Honorary Member of the Society, and calling my attention to By-Laws 14 and 19.

I beg to tender my grateful thanks to the Canadian Society of Civil Engineers, for the very distinguished honour they have conferred upon me by unanimously electing me an Honorary Member of the Society.

I have the honour to be,

Yours faithfully,

CHAS. A. HARTLEY.

HENRY T. BOVEY, Esq.,
Honorary Secretary.

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5 Great George Street,
WESTMINSTER, S.W., 21st June, 1889.

DEAR SIR,

I beg leave to acknowledge the receipt of your letter of the 3rd inst., in which you inform me that, at a meeting of the Society on the 23rd May, I was unanimously elected an Honorary Member of the Canadian Society of Civil Engineers.

I shall be glad if you will kindly convey my best thanks for the honour which the Society has thus done me, and say that I have great pleasure in accepting the election.

I am, dear Sir,

Yours truly,

FREDERICK BRAMWELL.

PROF. BOVEY, M.A., Hon. Sec.

THE UNIVERSITY, GLASGOW,
June 15th, 1889.

DEAR MR. BOVEY,

I have to-day in London received your letter of the 3rd, announcing that I have been elected an Honorary Member of the Canadian Society of Civil Engineers, and I write to you in reply to ask you to communicate to the Society my hearty thanks for the honour it has done me, and to say that I accept the appointment with much pleasure. Believe me,

Yours very truly,

WILLIAM THOMSON.

2 Queen Square Place,
WESTMINSTER, Dec. 2nd, 1889.

DEAR SIR,

I have received your letter of the 15th November, conveying to me the gratifying intelligence that the Canadian Society of Engineers have unanimously elected me an Honorary Member of the Society.

I beg you to communicate to the Society my appreciation of the high distinction they have conferred upon me.

Yours very truly,
JOHN FOWLER.

H. T. BOVEY, Esq.

BELGRAVE MANSIONS, S.W.,
Dec. 2nd, 1889.

DEAR SIR,

I have to acknowledge the receipt of your letter of the 18th ult., informing me that the Canadian Society of Civil Engineers had elected me an Honorary Member of the Society.

I beg to return my thanks for the honour that has been conferred upon me, which I assure you I greatly appreciate.

I am, dear Sir,
Yours very truly,
JOHN HAWKSHAW.

PROF. BOVEY, M.A.,
Sec. Can. Soc. C.E.

The Council again feels it an imperative duty to direct the attention of members to the qualifications required for admission into the several classes. As regards the *Student* class, it is considered that a candidate should have a good general education. He should be able to express himself clearly and grammatically, should have a knowledge of elementary mathematics and mechanics, in fact should be capable of undergoing an examination equivalent to that required for the matriculation into the Arts or Science Department of a University, as specified in the By-Laws.

The qualifications for admission into the classes of *Members* and *Associate Members* are still more important, and should be rigidly exacted. Corporate members, before attaching their signatures to a form of application for admission into the Society, should make it a rule to verify the accuracy of the statement of the candidate's professional career, and should further satisfy themselves that, if admitted, he would prove a fit and proper member of the Society. This is especially necessary, as, in many cases, the applicant is personally unknown to the members of Council. It would also greatly aid the Council in

coming to a decision, if the proposers would, in *every case*, communicate, through the Secretary, their views as to the proper classification of the candidate.

A careful adherence to these principles will do much to maintain that high standard which *esprit de corps* and patriotism alike demand should be jealously guarded in a national society.

The same motive which leads to the exclusion of ineligible applicants will induce members to take every method to secure men who will be worthy of the Society, and who will be likely to contribute to its permanent advancement. There seems to be ample opportunity for this kind of effort, in filling the ranks of the class of Associates, which offers a means of gaining the co-operation of men distinguished in the kindred sciences, or interested directly or indirectly in the development of the material resources of the country.

BRANCHES.

The Council notes with much satisfaction that a branch has been established in the City of Toronto. This result has been largely due to the efforts of Mr. A. Macdougall, who, from the first, has taken a deep and practical interest in the welfare of the Society. It is greatly to be desired that the example of Toronto should be speedily followed in other leading centres, as the discussion of the various papers at such centres will much enhance the value of the Transactions, while the holding of meetings will necessarily call out more practical interest in the working of the Society.

The Council is also still convinced of the truth of the principle which led the original framers of the constitution to provide for the establishment of branches, viz., that the national character of the Society would be best preserved by giving it a local hold in different parts of the Dominion.

ANNUAL MEETING.

The Third Annual Meeting was held on the 17th January, 1889. The morning session was devoted to the transaction of the business of the Society, and in the afternoon the retiring President, the late Samuel Keefer, delivered an address on the Progress of Hydraulic and Railway Engineering, referring also to the present condition of Electrical and Sanitary Engineering.

As in previous years, the Annual Meeting was concluded by a conversazione held at McGill College. The Society was honoured by the presence of His Excellency the Right Honourable Lord Stanley of

Preston, to whom an address was presented by the President, Colonel Gzowski, A.D.C., in the name of the Society.

A large number of guests were entertained on this occasion.

ORDINARY MEETINGS.

During the year 1889, sixteen ordinary meetings of the Society have been held, at which the following papers were read:

On "The Panama Canal," by E. Deniel; on "Cantilever Bridges," by C. F. Findlay; on "The Development of the Locomotive," by the late T. T. Vernon Smith; on "Work-shops, their Design and Construction," by J. Davis Barnett; on "The Colonial Government Dry Dock, St. John's, Newfoundland," by H. C. Burchell; on "The Esquimalt Graving Dock Works, B.C.," by W. Bennett; on "Bridge Calculations," by H. E. Vautelet; on "The Design and Construction of the Avon Bridge (N S.)," by R. F. Uniacke; on "The Cornwall Canal," by the late S. Keefer; and on the "Vancouver Water Works," by H. B. Smith.

The discussions have been animated and well sustained, but there is always room for improvement in this direction. The Council cannot too often remind members that their duty to the Society requires them to contribute any information they may possess on the subjects under consideration.

STUDENTS' MEETINGS.

There have been four students' meetings, at which papers were read on "Locomotive Construction," by J. P. Tuplin, B.A.Sc.; on the "Grand Trunk Ry. Double Track," by A. W. Strong, B.A. Sc.; and on "Wood Fibre for Paper-making," by F. A. Bowman.

Of these, Mr. Tuplin's Paper and Mr. Bowman's Paper have been considered by the Council worthy of record in the Transactions.

ACCOMMODATION.

During the past year, the meetings of the Society have again been held in rooms at McGill College, for the use of which the Society is much indebted to the Board of Governors. The Council, however, has long considered that the growing requirements of the Society, and the need of a library, in which the books could be consulted with convenience, rendered it most desirable that the Society should possess rooms of its own. This has now been made possible through the liberality of your President, Colonel Gzowski, and the Council has therefore secured the lease of the first floor of the new Bank of Montreal building, at the corner of St. Catherine and Mansfield streets, for a term of five years. It will be observed that the rooms are in a good

central position, and it is hoped that the natural result will be an increased attendance at the regular meetings.

It is expected that the rooms will be ready by the 1st of May, and that such arrangements will have then been completed as will make them at all times available for the use of members.

LIBRARY.

A number of donations to the Library have been received, and of especial value are:

Fifteen volumes of various works on Engineering, from Colonel Gzowski, President.

A complete set of the Tenth Census of the United States, consisting of thirty-four volumes, through your President, from the U. S. Government.

Eight volumes of Van Nostrand's Magazine (1869-76), and *seven* volumes of Reports of Commissioners of Public Works and Public Works Reports (1844-1870), from the late Samuel Keefer.

Volumes I. to VII. of the Transactions of the American Society of Mechanical Engineers, from the Council of the Society.

Nine volumes of Specifications of Government Buildings, alphabetically arranged, from G. F. Baillairgé, Esq., Member of Council.

Mr. Baillairgé's donation is to be supplemented at an early date by additional volumes of specifications relating to Harbors and other works.

The collections are in bound volumes, and have been carefully arranged to meet the requirements of the engineer, to whom they will prove of the utmost value for purposes of reference.

The Council has also much pleasure in stating that your President has given a further proof of his interest in the Society, by intimating his intention of presenting to the Library a valuable collection of engineering works, as soon as the rooms shall be ready for their reception.

Donations to the Library have also been received from Messrs. H. Wallis, F. R. F. Brown, H. F. Perley, C. Schreiber, John Kennedy, M. Murphy, C. M. Odell, J. B. Francis (of Lowell), W. McNab, R. Hering, S. Fortier, R. P. Cooke, G. Lindenthal, etc.

Exchanges of publications, in addition to those previously announced, have been arranged with each of the following Societies:—

The Society of Civil Engineers, Paris, France.

The Liverpool Engineering Society, Liverpool, England.

The Manchester Association of Engineers, Manchester, England.

The Midland Institute of Mining, Civil and Mechanical Engineers, Barnsley, England.

The North-East Coast Institution of Engineers and Shipbuilders Newcastle-on-Tyne, England.

The Royal United Service Institution, London, England.

Another donation of historic interest has been presented to the Society by the late Samuel Keefer, viz., a painting of the Suspension, Bridge, which he designed and erected at Niagara.

It is also of interest to note that Mr. Keefer built the first suspension bridge on this continent, over the Chaudière at Ottawa.

The Society is also fortunate in possessing large portraits of its Presidents, and it is hoped that future Presidents will be able to leave the Society like pleasant mementos.

BUILDING FUND.

The Building Committee reports that, in response to the two appeals made to the members of the Society for aid to the Building Fund, it has received subscriptions to the amount of $3,323.00, as per annexed list. This amount has been contributed by 37 members, 13 associate members, 1 associate, and 21 students. From these statistics it is evident that the Society, as a body, has, so far, taken little interest in the movement. It is, however, very satisfactory to find that so high an average as $46.20 per subscribing member has been reached. Had all the members contributed in like proportion, the Building Fund would now have amounted to not less than $25,000. Members should bear in mind that no entrance fee is required on admission into our Society, so that an extra effort is necessary to meet emergencies such as the present.

Your President, Colonel Gzowski, has generously given $300.00 a year, for five years, towards the rental of rooms for the Society, but the Building Committee feels that no time should be lost and no efforts spared in raising the sum required for the purchase of a site and the erection of a building, so as to give a more permanent basis to the Society.

New subscription lists will be immediately issued to all who have not yet subscribed, and the Committee hopes, at the end of the present year, to report that there is no one on the rolls of the Society who has not done something towards aiding in a work so important to its well-being.

FINANCES.

The income for the year ended on 31st December, 1889, amounted to $3629.92, and the general expenditure reached $3075.95, leaving a balance of $553.97, which, together with the balance of $1948.92 brought forward from the year 1888, gives a total balance of $2502.89 to be carried forward.

CANADIAN SOCIETY OF CIVIL ENGINEERS.

ABSTRACT OF RECEIPTS AND EXPENDITURE FOR THE YEAR ENDING DECEMBER 31st, 1889.

Balance from Dec. 31, 1888			$1948 92
General Receipts.			
Subscriptions:—			
Arrears	$78 00		
Current	2711 00		
Advance	619 00		
Extra on local cheques	3 54	3411 54	
Repaid by Building Fund for stationery		9 75	
Extra "Transactions," &c., sold		122 98	
Donations to the Library		20 00	
Bank interest to Dec. 31st		65 65	3629 92 5578 84
Building Fund.			
Balance from Dec. 31st, 1888		1249 70	
Additional subscriptions		1420 25	
Bank interest to Dec. 31st		56 58	1476 83 2726 53
			$8305 37

HERBERT WALLIS,
Treasurer.

General Expenditure.			
Cost of printing "Transactions"		$1358 93	
Advance proofs of papers		124 60	
Extra copies of papers for sale		79 85	
Printing and stationery		382 78	
Postage, messengers, telegrams, cabs		322 09	
Expenses of Secretary		573 00	
Stenographer		105 00	
Janitor		39 50	
Furniture, books and rent of chairs for annual meeting		48 46	
Rent of telephone (6 months)		12 50	
Bank commission on local cheques		8 91	
Express charges, etc., on library books		20 ;	3075 95
Building Fund.			
Stationery and Bank commission			11 05
Balance.			
General Fund	2502 89		
Building Fund	2715 48		5218 37
			$8305 37

Examined with books and vouchers and found correct.

P. A. PETERSON,
K. W. BLACKWELL,
Auditors.

SUBSCRIPTIONS TO BUILDING FUND, TO NOV. 21st, 1889.

NAME.	CLASS.	PROMISED.
Armstrong, J. S.	M.	$20 00
Barlow, J. R.	"	50 00
Blackwell, K. W.	"	80 00
Brown, F. R. F.	"	60 00
Drury, E. H.	"	20 00
Duffy, A	"	20 00
Dodwell, C. E. W.	"	20 00
Dawson, W. B	"	10 00
Evans, E. A	"	50 00
Garden, G. H	"	20 00
Harris, W. D.	"	20 00
Hill, A.	"	25 00
Harkom, J. W	"	20 00
Howard, S	"	10 00
Hannaford, E. P.	"	100 00
Jennings, W. T.	"	100 00
Keefer, S	"	100 00
Lloyd, J. Y.	"	20 00
Leduc, D	"	20 00
MacLeod, M. H.	"	40 00
Massy, G. H	"	15 00
Macdougall, A.	"	25 00
Murphy, M.	"	40 00
McWood, W	"	100 00
McMillan, D.	"	24 00
Pim, J. P.	"	12 00
Poole, H. S.	"	20 00
Peterson, P. A.	"	100 00
Page, John	"	100 00
Ross, James.	"	500 00
Schreiber, C	"	100 00
Tate, R. F.	"	25 00
Trutch, Sir J. W.	"	100 00
Vallée, L. A.	"	20 00
White, J. H.	"	100 00
Webster, G. H.	"	20 00
Wallis, Herbert	"	100 00
		$2206 00
Allison, J. L.	A.M.	20 00
Bannister, H.	"	40 00
Davis, W. M.	"	20 00
Hooper, G. R.	"	40 00
Irwin, H.	A.M.	$20 00
Lesage, T. W.	"	20 00
Mackenzie, H. J.	"	20 00
Odell, C. M.	"	20 00
Ostler, C. H.	"	20 00
Smith, C. B.	"	40 00
Thompson, R.	"	20 00
Vanier, J. E.	"	30 00
Warren, J.	"	4 00
		$314 00
Reid, R. G.	A.	500 00
Ball, J. P.	S.	$4 00
Brooks, N. E.	"	10 00
Cartwright, C. E.	"	4 00
Childs, A. E.	"	20 00
Denison, W. S.	"	5 00
Dimock, A. H.	"	20 00
Gibbons, J.	"	5 00
Hopkins, M. W.	"	1 00
Haultain, H. E. T.	"	15 00
Jonah, F. G.	"	12 00
Kilgour, W. H. A.	"	10 00
Loignon, E.	"	20 00
Loignon, A.	"	20 00
Mickle, G.	"	10 00
McColl, R.	"	12 00
McGregor, J. H.	"	20 00
Redpath, P. W.	"	10 00
Rinfret, R.	"	20 00
Shillinglaw, W. H.	"	25 00
Sargent, C. D.	"	20 00
Williams, M. L.	"	40 00
		$303 00

RECAPITULATION.

Members	2206 00
Associate Members	314 00
Associates	500 00
Students	303 00
	$3323 00

It was moved by Colonel Gzowski, seconded by Mr. P. A. Peterson, and resolved :—

"That the Report of the Council be received, approved and printed in the Transactions."

It was moved by Mr. John Kennedy, seconded by Mr. L. A. Vallée, and resolved:—

"That the Society has learned with the deepest regret of the death of its past President, Samuel Keefer, in whom it has lost an ardent friend and supporter, and that the members of the Society desire to convey to his widow and relatives their sincere sympathy with them in their bereavement, and their hearty appreciation of the work of Mr. Keefer during a long, active and useful life."

The Secretary next read the following resolution from the Branch at Toronto:—

Resolution adopted by Toronto Branch at meeting 9th January, 1890.

"That this branch desires to express its sorrow on learning of the death of our late President, Mr. Samuel Keefer, to whom the Society is greatly indebted for his services as President and his contributions to the Proceedings of the Society.

"Mr. Keefer, during his long and honourable career of over half a century, had, at various times, carried out several of the largest public works of the Dominion, which stand as monuments to his memory and engineering skill, and this branch desires to send a message of sympathy to the parent society on the loss we have all sustained."

It was moved by Prof. McLeod, seconded by Mr. K. W. Blackwell, and resolved:—

"That the scrutineers of the ballot for the election of officers and members of Council be instructed to prepare their report in such a manner as to be able, in the event of amendment *d* to by-law 7 being carried, to give the information required by said amendment."

Letters having been read by the Secretary from Messrs. John Page and C. Sproatt, signifying the wish of these gentlemen to withdraw their names from nomination on the Ballot Lists for the election of officers and members of Council for the year 1890,

It was moved by Mr. E. P. Hannaford, seconded by Mr. P. A. Peterson, and resolved:—

"That the scrutineers of the ballot for the election of the officers and members of Council be instructed to make no returns as to Messrs. John Page and C. Sproatt."

Upon the instructions of the President, the following legal opinion had been obtained and was read by the President:—

23rd January, 1890.

HENRY T. BOVEY, Esq.,

Sec. Can. Soc. C. E.

DEAR SIR,

The case submitted for our opinion we understand to be as follows:

The nominating committee of the Canadian Society of Civil Engineers, acting under the authority of by-law No. 6, issued to the members a list, Mr. Page being nominated by them as President. Mr. Page has since notified the committee that he withdraws his acceptance of such nomination. In view of the probability of there being no ballot cast for any other person as President, you desire to know what course of action the Society should follow in order to a valid election of a President at the annual meeting of the Society to be held to-day.

We should suggest either of the following courses of action:

1. The sealed letter ballots are, we think, by the terms of the by-laws under the control of the respective members (owners thereof) of the Society, until they are in the hands of the officer or scrutineer appointed at the meeting to open them. We would suggest that certain of these ballot papers be withdrawn, and the names of one or more members eligible for election to the office of President be substituted for that of Mr. Page on such ballot papers. This can be legally done, the nomination list being simply for guidance and not exclusive.

It being made known to the meeting before the sealed letter ballots are opened that Mr. Page has withdrawn his acceptance of nomination as president, the votes cast for him would be inoperative, and the choice of candidates would then be limited to these candidates having the greatest number of votes, and the voting upon such candidates could then be proceeded with in the usual way in terms of by-law No. 7.

2. If the remedy above suggested is not availed of by further nomination, than that of Mr. Page, we are of opinion that, as the by-laws do not provide any legal solution of the difficulty, the members of the Society may proceed to ballot for, and elect, any member eligible for the position of president in the usual way without reference to the by-law, and such election will be legal.

We remain, yours truly,

ROBERTSON, FLEET & FALCONER.

The meeting having resolved to adopt the course recommended by the above opinion, the corporate members withdrew their ballots and returned them, after having made such alteration therein as seemed advisable to the several voters.

It was moved by Mr. P. W. St. George, seconded by Mr. W. E. Gower, and resolved:—

"That Messrs. C. H. McLeod, J. M. Shanly, H. Irwin, G. H. Duggan, C. Leprohon and C. B. Reed be scrutineers of the ballot for the election of officers and members of Council for the year 1890."

It was moved by Mr. P. A. Peterson, seconded by Mr. H. D. Lumsend, and resolved :—

"That Messrs. A. P. Low, W. Whited, and E. A. Stone be scrutineers of the ballot for the amendments to the By-Laws."

The following were balloted for and elected the Nominating Committee for the year 1890 :

F. L. Wanklyn, Montreal.
C. Schreiber, Ottawa.
A. Macdougall, Toronto.
M. Murphy, Halifax.
P. Summerfield, Victoria, B. C.
T. C. Keefer, Past President, Ottawa.

The following Report of the Committee, anent the Summer Convention, was read by the Secretary of the said Committee, Mr. W. McNab :—

MONTREAL, 22nd January 1890.

PROF. H. T. BOVEY,
Sec. Can. Soc. C. E.,
Montreal.

Re Proposed Summer Convention.

DEAR SIR,

I have much pleasure in enclosing you the Report of the Summer Convention Committee, and in attaching a letter from Mr. Alan Macdougall of Toronto, dated Jan. 11th.

I may add that of the opinions received from members of the Society in regard to location for a Convention

57 per cent. were in favour of Toronto.
12 " " " " " " Montreal.
12 " " " " " " Niagara Falls.
6 " " " " " " Quebec.
6 " " " " " " Ottawa.
3 " " " " " " Lower Provinces.
3 " " " " " " Western Pacific points.
1 " " " " " " New York.

And in regard to the time of year :—

For month of May 7 per cent.
June 48 " "
July 13 " "
Aug. 14 " "
Sept. 17 " "
Oct. 1 " "

Yours faithfully,
W. McNAB,
Secy. to Committee.

30 ADELAIDE STREET EAST, TORONTO,

11th January, 1890.

Re Can. Soc. C. E. Summer Convention.

W. McNab, Esq., C. E.,
G. T. Ry., Montreal.

DEAR SIR,

The following resolution was passed on the 9th :—

That this branch do now invite the members of the Society to meet in Toronto, not later than the third week in June of this year, and hold their Convention in this city under the auspices of this branch.

I have much pleasure in personally indorsing this. When you bring it before the Society, say that June is in every way the best month for the Society to come here. I have had to arrange for the visits of British Association, American Public Association and American Association for the Advancement of Science, all of which took place in the end of August and first week of September, and it has been very hard work to "do" the thing properly. In the early part of June everybody is in town, and visitors will be much better entertained.

Faithfully yours,

(Signed), ALAN MACDOUGALL.

MONTREAL, 22nd January, 1890.

TO THE COUNCIL AND MEMBERS OF THE CANADIAN SOCIETY OF CIVIL ENGINEERS:

Your Committee, appointed at the regular meeting of the Society held on, the 5th ult. to take into consideration, and report at the Annual Meeting upon the advisability of holding a Summer Convention, and to make recommendations as to time, place, etc., beg to submit the result of their deliberations and enquiries as follows :—

1st. That in order to promote closer professional relations and more intimate personal acquaintance amongst the members, resident and non-resident and to more largely extend the influence and sphere of the Society, a Summer Convention should be held.

2nd. That in regard to the time of the year for holding such, the third or fourth week in June is recommended as the most suitable.

3rd. That the first Convention should be held in Toronto, that city affording special advantages, and being more centrally situated, besides having a branch of the Society already established there; but that the time and place of subsequent Conventions should either be determined by a vote of the members at the Annual Meeting immediately preceding it, or arranged by the Council with reference to the convenience of members connected with the place selected.

4th. That the Presidential Address be not made a feature of the Convention, but reserved, as at present for the Annual Meeting. It is recommended, however, that short papers might be prepared specially for the occa-

sion, read and discussed, and visits of the Society be made to such points of engineering or scientific interest as exist in the section of the country where the Convention may be held.

The whole respectfully submitted.

Per W. McNab, under authority

John Kennedy, Chairman.
Alan Macdougall.
W. P. Anderson.
W. McLea Walbank.
F. Came.
G. A. Mountain.
W. McNab, Secretary.

It was moved by Mr. R. Surtees, seconded by Mr. P. W. St. George, and resolved:—

"That the Report of the Committee anent the Summer Convention be received and adopted, and that the Council be requested to take the necessary steps to carry out the recommendations therein contained."

Notice was given of the following proposed amendment to By-Law 6:—

Line 7.—Strike out the words "who are neither elective officers nor candidates for office."

Proposed by W. L. Scott, G. H. Garden, W. Skaife, H. D. Lumsden, P. A. Peterson, P. W. St. George, R. Forsyth, John Kennedy, St George Boswell, W. J. Sproule.

The scrutineers of the ballot for the amendments to By-Laws reported as follows:—

(*a*) By-Law 6, line 13, etc.—Instead of "The list shall contain twenty-six names," read, "The list shall contain at least twenty-six names." *Carried by* 76 *per cent.*

(*b*) By-Law 6, line 16, etc.—Following "nineteen for councillors," insert "It shall be the duty of the nominating committee to accept as nominated for any office, any eligible candidate whose name is submitted on or before October 30th with his consent, by five or more members;" and instead of "such names shall be forwarded to the Council," read. "all names nominated shall be forwarded to the Council." *Carried by* 75 *per cent.*

(*c*) By-Law 6, line 21.—Instead of "The nomination list shall be signed by a majority of the nominating committee," read "The list of names nominated by the nominating committee shall be signed by a majority of that committee. *Carried by* 91 *per cent.*

(*d*) By-Law 7.—Following the words "declared at the Annual Meeting," add "and the report of the scrutineers shall give all names

that have received five or more votes and the number of votes cast for each." *Carried by* 67 *per cent.*

(*e*) By-Law 38, line 9.—After the words "31st December preceding," add "also a list of the meetings held by the Council, and the names of those present at each meeting." *Carried by* 76 *per cent.*

(*f*) By-Law 16.—Instead of the last paragraph commencing "In every case" and ending "works," substitute "In every case the candidate must have held a position of professional responsibility for at least two years." *Carried by* 90 *per cent.*

(*g*) By-Law 21, line 10.—After "promoted," insert "This statement shall not be required from Associates." *Carried by* 87 *per cent.*

The scrutineers of the ballot for the election of officers and members of Council for the year 1890 reported that the following had been duly elected as:—

President.

Casimir S. Gzowski (*re-elected*), Toronto.

Vice-Presidents.

Edmund P. Hannaford, Montreal.

John Kennedy, Montreal.

Henry F. Perley, Ottawa.

Treasurer.

Herbert Wallis.

Secretary.

Henry T. Bovey, M.A., F.R.S.C., Montreal.

Librarian.

Francis Chadwick, Montreal.

Members of Council.

William P. Anderson, Ottawa.
John D. Barnett, Stratford.
Kennet W. Blackwell, Montreal.
Francis R. F. Brown, Montreal.
Charles E. W. Dodwell, Montreal.
William T. Jennings, Toronto.
George A. Keefer, Vancouver, B.C.
H. G. C. Ketchum, Amherst, N.S.
George H. Massy, Montreal.
Thomas Munro, Coteau Landing.
Peter A. Peterson, Montreal.
Henry N. Ruttan, Winnipeg.
Percival W. St. George, Montreal.
Sir Jos. W. Trutch, Victoria, B.C.
Edmund Wragge, Toronto.

It was moved by Mr. J. H. Taylor, seconded by Mr. R. Surtees, and resolved:

"That the thanks of the meeting be tendered to the scrutineers, for the able manner in which they have performed the duties entrusted to them, and that the ballot papers be destroyed."

It was moved by Mr. E. P. Hannaford, seconded by Mr. F. R. F. Brown, and resolved:—

"That the meeting grants the Council power to incur the necessary expenses of rental, to enable the new rooms of the Society to be furnished and the Library to be properly catalogued, together with the expense required to make provisions for such attendance at the rooms as will render them available to members."

The meeting then adjourned until three o'clock.

AFTERNOON SESSION.

At three o'clock the meeting reassembled in the Lecture Hall of the Peter Redpath Museum, and Colonel Gzowski, President, delivered the Annual Address.

At the conclusion of the Address it was moved by His Excellency the Right Honorable Lord Stanley of Preston, seconded by Sir William Dawson, and unanimously resolved:—

"That the best thanks of the Society be presented to our President, Colonel Gzowski, for his untiring efforts in the interests of the Society during the past year, for the practical aid he has generously given towards its establishment on a firm foundation, and for the very able and interesting Address he has this day delivered."

It was moved by Mr. H. D. Lumsden, seconded by Mr. J. S. Armstrong, and resolved:—

"That the thanks of the Society be presented to Mr. Herbert Wallis for his services as Treasurer during the year 1889."

It was moved by Mr. St. G. Boswell, seconded by Mr. A. J. Lawson, and resolved:—

"That the thanks of the Society be presented to Prof. Bovey for his services as Secretary during the year 1889."

It was moved by Mr. J. H. Taylor, seconded by Mr. J. E. Vanier, and resolved:—

"That the thanks of the Society be presented to Mr. Francis Chadwick for his services as Librarian during the year 1889."

Messrs. Wallis, Bovey and Chadwick made appropriate replies, thanking the Society for its expressions of approval.

On the motion of Mr. Hannaford, seconded by Mr. Kennedy, a cor-

dial vote of thanks was presented to His Excellency Lord Stanley, for having consented to be present at the Society dinner on the 23rd inst. and at the delivery of the President's Address.

The President, in closing the proceedings, thanked Sir William Dawson for the kindness he had shewn the Society in giving it a home in McGill University during the last three years.

The meeting was then adjourned.

PRESIDENT'S ADDRESS.

The established custom of the Society being for the retiring President to deliver an Address, I shall make an effort to follow the example of my predecessors. Before entering upon the subjects to which I hope to secure your brief attention, I must express my grateful appreciation of the cordial manner in which I was offered the highest position in the gift of the Society, and my warmest thanks for the unanimity with which you called on me to preside over it. The progress of the Society since its recent organization has been very gratifying. The Roll of Members, as you will have observed from the report of the Council, is as follows:—

Honorary Members	7
Members	265
Associate Members	102
Associates	62
Students	152
	588

A number of original, interesting, and valuable papers on Engineering subjects have been read and discussed at the regular meetings, which have been fairly attended. As this has all been achieved in the first three years of the life of our Society, I submit that it furnishes unquestionable and encouraging evidence of its usefulness and popularity. Our Honorary Members are all men of such marked distinction as to do honour to the Society. The first who accepted election was his Excellency Lord Stanley of Preston, G. C. B., Governor General of the Dominion of Canada. His Excellency's acceptance of Honorary Membership of our Society is a valuable and gratifying compliment to, and affords evidence of appreciation of, the Engineering profession. The next was Sir William Dawson, C. M. G., the learned President of McGill University, to whom the Society is under great obligations for the generous hospitality he extended by giving our Members a home within the University Buildings, which proved a great advantage in the formative period of the Society's existence.

As those Honorary Members who belong to our Profession have all joined our ranks since my accession to the office of President, I may be permitted to make a brief reference to their record and distinctions.

Sir Frederick Bramwell, besides his eminent talents as an engineer, has won unrivalled fame from his faculty for technical exposition, combined with oratorical powers of illustration—he is indeed one of the brightest lights of the Profession.

Sir Charles Hartley, the distinguished hydraulic engineer, is famous not only in England, but on the continent of Europe, having been selected by England, Austria, and Russia to act as chief engineer on the Commission for the improvement of the navigation of the River Danube.

Sir John Fowler's name is honourably familiar to the Profession as that of the designer of many important and difficult engineering works, more especially the one approaching completion—the great Bridge over the Forth. This unique and magnificent monument of scientific genius and engineering talent, daring, and skill has carried the art of spanning wide spaces much further than was heretofore conceived as practicable.

Sir John Hawkshaw is one of the oldest and most eminent members on the roll of the Mother Society. The Severn Tunnel, just completed, bears striking evidence of his great engineering skill. It is well expressed in the dedication to him of the late Mr. Walker's book on the Tunnel in the words, "To Sir John Hawkshaw's professional skill and indomitable perseverance, the Severn Tunnel will ever remain a lasting monument."

I must not pass by the name of Sir William Thomson, who enjoys a world-wide reputation as an eminent scientist. He is especially famous as the electrician by whose exhaustive experiments the exact measure of electric power was arrived at, which enabled the submarine cables to be as effective as they now are. Indeed we owe to his researches and skill the marvellous facility for almost instantaneous communication enjoyed with all parts of the world. The Society has every reason to be congratulated upon, and take pride in, the representatives of Engineering talent on her roll of Honorary Members.

The Addresses of my two predecessors have so exhaustively treated the different branches of the Profession with reference to men and the works with which they were associated in Canada, that I find it difficult to say anything new and interesting about them, for although Canada has not ceased to make progress, nor her Engineers to design and carry out works which evidence their ability, one or two years is

too short a measure of time to allow of sufficient development of new projects for the text of an Address, or any extended notice of such enterprises. At a meeting of the British Association last year, after being introduced by Sir Henry Roscoe and inducted into the President's Chair, Sir Frederick Bramwell commenced his brilliant address by saying: "The late Lord Iddesleigh delighted an audience for a whole evening by an address on 'Nothing.' Would that I had the talents and could discourse to you as charmingly as he did to his audience, but I dare not try to talk about 'Nothing'." In the same spirit I may say: "Would that I had the literary gifts of Sir Frederick, and could discourse to you as charmingly as he did to the British Association."

But lacking those powers for which he is so famed, I will ask your indulgence while I offer some observations, first, upon a work of considerable magnitude, to which my predecessor, the late Mr. Samuel Keefer, made a very brief allusion in his Address,—I refer to the Railway Tunnel under the River St. Clair. That interesting work was then in but a very early stage of progress. Since that time it has advanced very rapidly. This tunnel is the first important engineering work of that description in Canada. It contains some novel features of much interest to our Profession.

The work is in charge of, and is carried on by a Canadian engineer, who is a Member of our Society, Mr. Joseph Hobson, Chief Engineer of the Great Western Division of the Grand Trunk Railway. The Tunnel under the River St. Clair is designed to connect the Grand Trunk Railway system in Canada with that portion of its organization which is in the United States, extending as far as Chicago. The object of the tunnel is to do away with the necessity of the present costly ferry for passengers and freight at Point Edward, at the foot of Lake Huron, which during the winter occasions much delay from accumulations of ice. The organization under which the undertaking is carried on is a chartered company under the laws of the State of Michigan and of the Dominion of Canada.

About the year 1884 Mr. Walter Shanly, a member of our Society, reported upon the project. He recommended locating it below Sarnia, very near the spot where the tunnel is now being constructed, but he made no survey. Under instructions from Sir Joseph Hickson, the President of the Tunnel Company, Mr. Hobson made the necessary survey in 1884, and finally located the line along which the tunnel is now being driven. An arrangement was made by the Tunnel Company with the well-known Engineer, General William Soy Smith,

drive a temporary adit as a trial to ascertain the nature and quality of the material likely to be encountered, especially under the River St. Clair. This adit had only been partially carried out when a flow of gas was met, which caused the work to be abandoned. The Tunnel Company subsequently decided to carry out the work themselves under the direction of their Engineer, Mr. Hobson.

Learning of the decision to drive a full-sized tunnel for a single line of rails, work for which was to be commenced and pursued at both ends, and that the tunnel was to be lined with cast-iron flanged plates, a novel mode of lining in America, and only used in two tunnels of small dimensions in England, I decided to personally examine the work. I waited, however, until it was sufficiently advanced to enable me to see it in full operation. Having visited the tunnel, it occurred to me that an account of the progress already made, with other particulars in connection with this large work, would be of interest.

The total length of the tunnel with approaches will be 2 miles and 1145 feet. The length, from face to face of the portals, is 6.000 feet. The depth of open cutting at the East or Canadian side of the tunnel is 62 feet; at the West, or United States end, 52 feet. The length of that part which is under water will be 2310 feet, with a gradient to the West rising one foot in one thousand. The greatest depth of the River St. Clair on the line of the tunnel is forty and one half feet. The minimum thickness of the roof is 16 feet. The bottom of the tunnel is about 10 feet above the rock underlying the clay. This has been ascertained by very accurate soundings and borings taken near the line of the tunnel at each 20 feet. It may be well to say that the flow of gas was found immediately above the rock, indicating that its source was in or below that strata, the gas escaping through fissures in the rock. Locating the bottom of the tunnel above the rock, and yet securing sufficient thickness of material to support the roof, was in order to avoid meeting with gas.

The material through which the tunnel is driven is clay, with pockets of wet sand and gravel. Large boulders are occasionally encountered. The clay varies in quality, changing from hard to soft so abruptly, that one side of the shield works sometimes in hardpan while the other side is in material of the consistency of putty, so soft as to flow under the pressure of the superincumbent weight. The borings that have been made in the bed of the river parallel to the axis of the tunnel indicate that the material as described will be found throughout. The tunnel in cross section is circular with an inside diameter of 19 feet 10 inches. It is a circular tube, lined throughout with flanged plates of cast-iron

two inches thick, five feet long, bolted together. The ends of these plates are planed to make a close joint, and before being used they are heated and soaked in tar. The lower half of the lining is encased outside in three inches of grout, formed of the best Portland cement and coarse sharp sand. Holes are made in the upper part of each plate through which the grout is poured in. Under the river the whole of the outside of the cast-iron lining will be covered in this way.

In the prosecution of the work an iron shield is used, under the protection of which the excavation is carried on and the cast-iron lining is put together. The shield is just large enough to enclose the cast-iron lining, and as the excavation in front of it is advanced, it is moved forward just far enough to put together one section of the tunnel lining. As the width of these sections or rings is only 18 inches, and as the rear portion of the shield which encloses the lining overlaps it 39 inches, the forward end of the lining is always within the shield. To ensure safety as far as possible in the event of a sudden strong flow of quicksand or water, an iron diaphragm or bulkhead is built across the shield 48 inches from the rear of it, with two sliding doors which can at once be closed. To give an intelligible description of the shield would require drawings, but it may be said that it differs in many respects from Barlow's, Greathead's and Beache's shields, the construction of each having been carefully examined. It is made entirely of steel, its weight being about 80 tons.

Close to its circumference, and just outside the outer shell of the shield, there are placed 24 hydraulic jacks, so that the rams can be worked against the finished iron lining of the tunnel when the shield has to be moved forward. These rams are operated by steam force pumps, and can be used singly, in groups, or altogether. The cocks controlling them are so placed that one man can work 12 of them without changing his position. The aggregate power of the 24 jacks in the shield is 3,000 tons, which is immensely in excess of what is required to move it. But it has been found during the progress of the work that, when a nodule of extremely hard material is met with, the work has to be done by a small group of jacks at the point where the hard clay is encountered. Although, as I have already said, the shield differs materially from all other shields, its circular form and mode of propulsion by jacks is common to other shields. An ingenious arrangement is provided, to show whether the position of the shield is maintained in the direct line of the tunnel. Deviation from the right line is ascertained by measurement, and is marked on a diagram prepared for this purpose, which is kept as a record. One of these measurements for record is made daily,

after placing the last section of the lining for that day's work. Any deviation is corrected next day by working the shield to the right or left, lifting it or lowering it as may be necessary. Thus far, the deviations have been very trifling, not exceeding two inches in any direction. The average rate of progress at the two ends of the tunnel has for some time been 15 feet per day of 24 hours. The rate is wholly dependent upon the character of the material met with. On a face of twenty-one and a half feet in diameter, the size of the shield, only 16 men can excavate at a time. The removal of the clay, after it is cut out, as well as putting in the lining, appears to be done without any difficulty or delay. The men have already become so expert in the work of excavation, as well as in placing together the cast-iron segments forming the lining, that, under ordinary circumstances, they can complete a full ring in one hour, sometimes in a less period. I found the tunnel quite dry. Provision is made during construction to catch the rain water that falls into the open cutting at each end of the tunnel, into wells at the portals, from whence it is pumped by steam power into channels at the top of the slopes. It is also thoroughly ventilated. Fresh air is supplied by blowers with a capacity of 600,000 feet of air per hour.

The total length on both sides of the river of the completed tunnel to the 22nd of January is 2006 feet, in Canada 844 feet, in the United States 1162 feet. In a work of this character it is very difficult to make a reliable estimate of cost at so early a stage of progress, but it is believed that the cost of the tunnel completed with approaches and permanent way will be about $2,500,000. Future difficulties, particularly under the river from gas and water, also the system of ventilation, have been very carefully considered, and provision is made to meet them. The time named for the completion of the tunnel is July, 1891.

In the Address of my predecessor, the late Samuel Keefer, a short reference is made by him to the great cantilever bridge across the Forth, constructed by Sir John Fowler and Mr. Benjamin Baker. Having been engaged in the construction of an important railway bridge across the Niagara River, the International Bridge, more especially in the treatment of sub-aqueous foundations, where I made a novel use of well-known appliances, anchors and chains, in accurately locating and founding the caissons for piers, I became very much interested in the construction of the Forth Bridge. That gigantic monument of engineering skill, which has upset all former theories on the dimensions of rigid spans for bridges, deserves, I think, a more extended

notice to be placed among the records of our Society. With that object in view I obtained from Mr. Baker information with permission to use it, which enables me to give a brief account, free from technicalities, of this great work, that may prove interesting and instructive.

The bridge across the Frith of Forth is at this date a bridge with the largest spans in the world. Its total length is 7098 feet 6 inches, made of two spans, each 1700 feet in the clear, the remaining distance is covered by iron lattice girders on stone piers. Its construction was the outcome of railway competition. The Frith of Forth at Edinburgh being from one to five miles wide blocks the direct line of the East Coast railways. Traffic must either be diverted many miles, or cross the stream in ferry boats. The Forth Bridge will make the line of which it forms a part continuous. Its construction was long delayed, owing to the great width and depth of the Forth. It is not easy to realize how vast is the difference between a bridge with a 1700 ft. span and the largest span of a railway bridge hitherto constructed. The height of the steel work is also exceptionally great, being equal to that of the golden cross at St. Paul's, 360 feet, while the total height of the bridge is just equal to that of the Great Pyramid, 460 feet. As regards the principle of design, "Cantilever" is a 200 year old term for a "Bracket," and the Forth Bridge spans are made up of two brackets and a connecting girder. On these brackets there is a horizontal pull of 10,000 tons, and on their bases rests a weight of 100,000 tons. The principle of bracket and girder construction is as old as the hills, as it lends itself particularly to timber construction, which preceded masonry. A wooden bridge built 230 years ago in Thibet, with a span of 182 feet, was the true prototype of the Forth Bridge, which only became possible when Bessemer steel was invented. One of the advantages of the cantilever system is facility and safety of erection, as such bridges can be built by commencing at the piers and adding successive bays of the cantilever right and left until the whole is completed. There is thus no moment when the safety of the whole structure is dependent upon the integrity of some temporary staging. At first glance one might think that a cantilever or bracket was not adapted to carry great weights or for long spans. But in long spans the dead weight of the structure itself is the most important element, and since a bracket requires to be the strongest at the root, and lightened out towards the point, it follows that the main weight of the cantilever lies towards the support and acts at a relatively small leverage. The cantilevers or brackets of the Forth Bridge are enormously strong. Mr. Baker says that half a dozen iron-clads might be hung upon them.

The works of the bridge were commenced in 1883. Mr. Arrol, of Glasgow, was the contractor. A start was made with the pier work simultaneously with the erection of shops and machinery for the manufacture of the superstructure. Each main pier consists of a group of 4 cylindrical masonry piers about 70 feet diameter. These are founded on rock or hard boulder clay at depths ranging up to 90 feet below high water. Six of the cylindrical piers were put in place by the use of compressed air. The piers were floated into position by building them hollow in the first instance, and filling them with solid masonry subsequently. The whole was enclosed in a bottom placed about 7 feet above the external cylindrical skin, so that a huge diving bell, 70 feet in diameter and 7 feet high, constitutes the bottom of each pier. When in position the water was driven out of the chambers by forcing in compressed air. Workmen then entered through air-locks, and carried on the excavation 90 feet below the waters of the Forth.

Mr. Baker describes the fixing of one of the piers thus:—"A huge iron caisson, 70 feet in diameter and about 50 to 60 feet high, was built on launching ways like a ship. The bottom of the caisson was set up 7 feet above the cutting edge, and so constituted a chamber 70 feet in diameter and 7 feet high, capable of being pumped full of compressed air." The iron work weighed about 500 tons, and when towed out into position the concrete and brick work added brought the total weight up to 2700 tons. Additional concrete was then filled in, and when the weight reached 3300 tons, the caisson grounded on the sea bottom, where a bed had been prepared for it with sand bags. The workmen then entered through air locks, and the excavation work proceeded in an electrically lighted chamber. The barometer is considered high at 31 inches, but in the working chamber it often stood at 72. It may be interesting to remark that when Coxwell, the aeronaut, made his high ascent, the barometer fell to 7½, or about one-tenth of the height named, which illustrates how marvellously the human body is adapted to sustain wide variations of atmospheric pressure. The superstructure of this gigantic bridge required the manufacture on the spot of 50,000 tons of steel girders and other work. As a rule the *compression* members consist of tubes, and the *tension* members of lattice girders; and this arrangement from an architectural point of view proved most effective. The central connecting girder was erected in two halves temporarily connected with the projecting ends of the cantilevers. The bottom members of the two halves, at the centre of the 1700 ft. span, had large holes bored in them, for the insertion of pins to connect the two projecting halves of the bridge, each of course 850 feet long. These

holes had to be watched so as to seize the right moment when the varying temperature and consequent expansion of the steel brought them opposite each other, so that the pins could be dropped in. The next thing was to release the temporary ties holding the top members of the central girder to the cantilever. These were steel bars three feet wide and two inches thick; to cut through such section of steel would have taken a long time. Mr. Arrol, the contractor, arranged portable oil furnaces by which the ties could be made white hot in a short time, and so the strain on the ties was relieved as effectually as by cutting them. Mr. Baker admits that the cost of the bridge exceeded the estimates. He claims that this was not an exceptional thing, and says that if such a bridge had to be built again, time and money might both be saved. It is expected that trains will begin to run over the bridge in March next. Before concluding a reference to this great bridge, I may add that last year a charter was granted for a 2800 feet span bridge at New York.

This year, Messrs. Schneider & Company of Creusot, in conference with Sir John Fowler and Mr. Baker, as consulting engineers, have designed the steel work of a bridge over the English channel, and Messrs. Hersent & Co., of Suez and Panama Canal fame, have designed the piers. The total length of the projected bridge is 24 miles, the number of piers 120, the width of the openings from 328 to 1640 feet, the clear headway for ships 180 feet, the greatest depth of water 180 feet, and the height from the foundations to the top of the steel work 600 feet. It is calculated that a trifle less than a million tons of steel would be required for this stupendous structure. The estimated cost of the bridge is £34,000,000 sterling.

The Forth Bridge is not only a lasting monument to the designers and constructors, but verifies and most forcibly illustrates the fitness of the motto adopted for the profession of civil engineer: "Whereby the great sources of power in nature are converted, adapted, and applied for the use and convenience of Man."

ELECTRICAL ENGINEERING.

Electricity as a science and electrical engineering are making very rapid progress to control that wonderful power in nature, for the use and convenience of man, which was so graphically described by Mr. Thomas Keefer, in his address to the Society, as "that force like steam, and like it chiefly known by its effects; its range is universal in the heavens above and the earth beneath, and apparently in all things

living, in all animal and vegetable life." It is not my intention to enlarge at present on the numerous improvements in the production and use of electricity for giving light and motive power. But it may be of interest to know that its use as a motive power is being very rapidly developed. One of the early practical satisfactory results of electrical power transmission was at Virginia City, Nevada, on the celebrated mining property, "The Comstock Lode," where water power from streams in the Sierra Nevada Mountains was found to be insufficient to work the stamp mills. A tunnel is driven into the mountain to a point at which a chamber is excavated out of solid porphyry, for the reception of dynamo electric generators and water wheels. This chamber is 50 feet long, 25 feet wide, and about 12 feet high. From the tank above the tunnel at an elevation of 1650 feet, containing waste surface water, two wrought-iron pipes are led to this chamber which supply water to wheels that drive the large dynamo generators, each of 130 horse power capacity, with sufficient numbers of them to generate in the aggregate 800 horse power which is transmitted to the stamp mills, and by this means they are doubled in number, and worked at 70 per cent. less cost.

As Chairman of the Commissioners of the Victoria Niagara Falls Park, I am in negotiation for the use of Niagara Falls to generate electricity in sufficient quantity and power to be transmitted to Buffalo, Lockport, Rochester, Hamilton and Toronto, there to be used as a motive power for working stationary engines at a greatly reduced cost per horse power. The project is to drive a tunnel under the Falls at a point about 165 feet below the upper level of the river, and at its termination excavate a large chamber for placing water wheels and dynamos. The supply of water to be from pipes leading into the tunnel, with a fall of about 160 feet. That an almost unlimited electric power can be generated by the use of Niagara Falls is not doubted. The transmission of that power to contemplated distances in an effective form is maintained by some electrical experts as quite practicable; there are others again who place a much shorter limit to the power of transmission. However that may result, there can be no doubt that the science of electricity and its uses is still in a very early stage of development.

Allow me to close my Address with a short reference to my own personal engineering experience in Canada. The very great progress Canada has made in the development of her canals, railways, and other public works within the last half century induces me to ask you to bear with me for a few moments, while I make some references to the condi-

tion of public works, more especially those in Upper Canada, now the Province of Ontario, in the year 1841, requiring the services of engineers. I do this for the purpose of contrasting the beginnings at that period with the magnitude of works accomplished with the aid of engineering skill as they are to-day. During the administration of the Government by the late Sir Charles Bagot, Governor General, I was appointed in 1841 in charge of construction of all kinds of roads, plank, macadam, etc., harbours, light-houses and bridges, not including the Welland canal; that work was under charge of my predecessor as President of the Society, the late Mr. Samuel Keefer, who at that time occupied the position of Chief Engineer of Public Works in Upper and Lower Canada, with the late Hon. H. H. Killaly as Chairman of the Board of Works. It was a period immediately after the negotiation of a loan for £1,500,000 stg. by the united provinces of Upper and Lower Canada. The proceeds were to be applied for the construction of public works in both provinces. The district containing works placed under my charge extended from Kingston on the east to Toronto, Hamilton, and the southern shore of Lake Erie on the south, Amherstburg and Sarnia on the west, Owen Sound and Penetanguishene on the north, in all containing 41 district works. A list of these will be found in the report of the Commissioner of Public Works for the year 1848, on page 50, accompanied by my reports on each. The amount expended on each of them varied materially, but in the aggregate amounted to about $2,000,000, which in those days was considered a very large sum.

The location, laying out, and supervision of this number of scattered works, with very limited assistance from willing and hard working men, in most cases with very little engineering knowledge or experience, was no easy task. The work was rendered more difficult by the impossibility of rapid communication, for from 35 to 40 miles a day, whether on wheels or in the saddle, sometimes for the greater part on foot, was considered a good day's journey. The existing roads in those days were in the occasionally cleared portions of the country, formed only with the material thrown out of small ditches and placed in the centre of the road allowance, without any regard to form; while in the uncleared portions of the country, which were by far the largest, the roads were made by cutting down trees for a certain width on each side of the centre line, but only blazing those standing on or near the boundaries of the 66 feet road allowance,—the statutory width for roads. The setting out of these allowances for roads was done with ordinary compass by amateur surveyors who practised in those days.

The act respecting land surveyors, requiring them to pass an exam-

ination before being allowed to practice, was not passed until 1849. Drainage, which by that eminent authority, McAdam, is considered to be the primary and most important condition in making a road, was not understood, and therefore altogether ignored. Where there was a wet spongy depression, it was filled with logs covered with a small quantity of earth that soon disappeared, leaving the logs bare. Such portions of a road were called "Corduroy," and were the dread of all who were obliged to travel over them. The length of time required for a journey and the discomfort of travelling over such roads can only be understood and appreciated by those who were compelled to go over them. I make this allusion to show the physical effort and endurance that were needed to visit the different works sufficiently often to see that they were being properly carried out. There were in all about 600 miles of varied classes of roads.

To show the novelty in those days of engineering works, I may be allowed to narrate an incident: I had to build a bridge across the River Thames near London, now within the limits of that city, on the road to Sarnia, to replace a temporary structure then in use. The new bridge was on the Howe truss plan with the roadway on the bottom chord, one span of 160 feet. When this bridge was completed ready for traffic, and just before the removal of the temporary one, I was waited upon by several leading citizens of London, who inquired if I had absolute confidence in the stability of the bridge to carry the heavy traffic that the improved condition of the road would bring upon it? They thought it too light and spidery. Fortunately batteries of Royal Artillery were quartered in London. I asked the commanding officer to take them across the bridge to test its strength. He replied, "Yes, if you will agree to stand under it." The batteries crossed the bridge at a walk, then at a trot, without even disturbing the camber. That established confidence in the bridge.

The introduction of plank and McAdam roads gave rise to a desire for better means of communication, as their construction gave such striking evidence of great saving of time by the ability to carry heavier loads more rapidly, with reduced wear and tear of horses and vehicles, hence with greater economy of carriage. This practical, beneficial evidence pioneered the way to the construction of railways, towards which counties, cities, towns and townships voted subsidies in the form of bonds towards the cost of building them. While plank roads were considered a novelty, investigation proved that the system was very ancient. The Prussian Minister of Education, having learned that Prof. Knoke found traces of old Roman plank roads in Lower Hanover,

had the matter fully investigated. Two plank roads were traced built across a moor. One of them showed signs of having been demolished by force, the boards, that originially were fastened to the bearers with trenails, having been violently torn away and buried in the bog. The other road seemed to have fallen into decay, but it appears to have been repaired during the Roman period. Those repairs, apparently, were done hastily, for in one place, a mallet, probably used to drive home the trenails, was found on the track. The local archæologists feel assured that they have here the "Pontes Longi" which were used A. D. 15 by the Roman commander in his retreat from Germany to Ems. In addition to the 600 miles of roads, such as I have referred to, six bridges were built which in those days were considered important structures; and six harbours, with lighthouses, four on Lake Erie and two on Lake Ontario, including the Burlington Bay Canal. The building of these harbours was a strong incentive to the movement for obtaining still more rapid communication to these points for shipment of agricultural products. Railways now extend to all of them. All these roads and works were completed about the year 1846. These references to the earlier stages of work for facilitating traffic, and to the condition of the country when in course of development, are given with the view of supplying some historic reminiscences, for the purposes of comparison with the present advanced state of public works, as well as those of private enterprise, accomplished by the aid of civil engineers.

After 1841 and 1842 there was a rapid development throughout Canada of large enterprises undertaken by the Government and private organisations. The first enlargement of the Welland Canal to 9 feet of water on the mitre sills was commenced in 1842. The earliest railway in Canada, the Laprairie and St. Johns, was built in 1836. The Montreal and Lachine Railway was opened and worked with imported English equipment in 1847. The St. Lawrence and Atlantic Railway (now the Grand Trunk), of which I was chief engineer, was opened for traffic to St. Hyacinthe in 1849. The first deepening of the straight channel in Lake St. Peter, upon which I reported with Sir William Logan, General McNeil, and Captain Child of the U. S. Engineers, was begun in 1850. The Byetown and Prescott Railway, known as the St. Lawrence & Ottawa, now part of the Canadian Pacific Railway, was commenced in 1851, and in the same year, the Northern Railway from Toronto to Owen Sound, as was also, about the same time, the Great Western Railway from the Niagara River to Windsor (now Grand Trunk). I will not enter into further details.

These improved means of communication, not only within the boundaries of the Dominion, now extending from the Atlantic to the Pacific, but with the neighboring Republic, have had a marvellous effect in accelerating the material progress of Canada by developing her natural resources in soil, forest, and mine, by stimulating manufacturing industries, and creating those commercial enterprises which have added so greatly to the stability and wealth of the Dominion. The canals of Canada, as a system of internal navigation, have not their equals in the world. As they add so largely to the carrying conveniences of the country, they reflect much honour on the engineering skill displayed in their construction. The St. Lawrence and Niagara Rivers are spanned by bridges that demanded engineering skill to design and erect. Canada has now in operation within her borders no less than 13,410 miles of railways, representing a capital of $727,180,443. In this vital necessity of rapid locomotion, the Dominion with its five millions of people is as fully and favourably equipped as the States with sixty-five millions.

It is interesting to mention that in a book published a few months ago, entitled "The Railways of England," by W. M. Acworth,—a work evidently popular, for I quote from the 2nd edition,—the year 1843 is named as marking the period of stable equilibrium and development of railways in Great Britain. At that date there were only 1829 miles in operation, nine-tenths of that mileage was in England. The capital authorized at that date was about £70,000,000, about 300,000 passengers were carried every week, and the total weekly receipts from all sources were somewhat in excess of £100,000. To-day there are nearly 20,000 miles of railway lines in Great Britain, seven-tenths of them in England and Wales. The paid up capital exceeds £800,000,000, and the annual receipts are greater than all the capital in 1843. The number of passengers has increased forty fold.

But vast as has been the development of Canada's capacities for meeting the needs of agricultural, mineral and industrial enterprises, and for providing the conveniences of ever enlarging commerce and of domestic life, the future will see even greater strides made in the material progress of our country. The works that have signalized the past only foreshadow those enlarged opportunities for usefulness and distinction which the future will open up to the civil engineer.

Permit me in conclusion to say a few words about our Society. The report of the Council shows a considerable increase in our numbers, This no doubt is highly satisfactory, from my own point of view, not only because of this increase, but as a proof that the Society is doing work that is appreciated by engineers, and that the work is good, for were

it otherwise they would not have joined us. During the year of my office as your President, I have to regret that owing to my residing at so great a distance from the head-quarters of the Society, and for other reasons beyond my control, I have done but little towards promoting the interests of the Society. This failure to do more has been from inability and not from earnest good-will towards or interest in the welfare of the Society. Allow me, however, to say that any effort of your President alone will not suffice to ensure success. He is powerless unless aided by members. Pardon me if I say that it is the duty of each one of you to help. Each member should bring before the Society every subject of interest connected with our profession of which he has experience in the course of his practice. He ought to attend the meetings for the reading and discussion of papers as frequently as possible. You will forgive me for these words of personal advice to every member. Although they come from one who was your nominal head but for the short term of twelve months, he is not wanting in age in other ways, and let me assure you that they are inspired solely by a desire that the transactions and papers selected by the Council for discussion should be worthy of the Society. They are the proper medium by which the Society's usefulness is to be maintained. By the printing and distribution of those papers our work becomes known, and by their merits new members are attracted. Accept the assurance that I will do all in my power to further the interests of the Society, and I shall watch its progress with anxious desire to see it prosper.

I cannot sit down without making an allusion to the death of my predecessor in the Presidency of the Society, Mr. Samuel Keefer, who was my warm personal friend, and the earliest professional colleague I had in Canada. During the period of my service in the Department of Public Works from 1841 to 1846, Mr. Keefer was my superior officer. I always found his advice sound and most valuable. He was devotedly fond of his profession to which he did honour. He left important engineering works, with which his name will always remain associated. His irreproachable life reached almost fourscore years, the limit allotted to man, leaving a good example to be followed by all members of our profession.

Thursday, 30th January.

JOHN KENNEDY, Vice-President, in the Chair.

Paper No. 87.

STAND-PIPES.

By R. S. Lea, Stud. Can. Soc. C.E.

In many systems of water-supply where the reservoir and the pumping station are at a considerable distance apart, a stand pipe is placed upon the force mains, to equalize the resistance against the pumps. The stand pipe, when used for this purpose, serves as a partial substitute for relief valves, acting in combination with tall and capacious air chambers. It is the office of the stand-pipe or of the air vessel to take up the excess and to compensate for the deficiency of delivery by the pump pistons, plungers, or buckets, and they are more effective the nearer they are placed to the pump cylinders.

The forward stroke of the piston of the single acting pump forces the water, not only along the pipes, but also into the lower part of the air vessel or into the stand-pipe, compressing the contained air in the one case and raising the column of water in the other. The energy stored up in this way is given out, during the backward stroke of the piston, to the advancing water in the main, sustaining its motion until the next forward stroke. The air vessel on the force main is practically a shorter closed-top stand-pipe containing an imprisoned body of air under pressure, instead of a heavy column of water; and neither of them is of so much importance where a double-acting pump is employed.

Tall, open-topped stand-pipes of wrought iron or steel are very generally employed, without reservoirs, in the construction of waterworks in the Western States, where the level character of the ground makes them necessary. They are also very often built in locations where the necessity for their use is not so evident. In such cases the choice between a reservoir, a tank, or a stand-pipe is often one which requires careful calculation, combined with judgment and experience. An earthen reservoir is always to be chosen where practicable, on account of its durable and permanent character. Where the site is

just a little too low to enable an embankment for a reservoir to be constructed, at a reasonable cost, a mound of earth is made artificially, and upon this foundation an iron tank is built, which maintains the surface of the water at the required elevation.

But in flat countries, or in situations where the nearest elevation is at too great a distance, some other method must be employed to get the requisite head. This may be done either by building a steel or iron stand-pipe high enough for the purpose, or by constructing an iron tank of large diameter compared with the stand-pipe, and supporting it at the proper elevation by a well braced iron tower. One advantage urged in favour of the elevated tank method is, that by making the diameter say 75 per cent. greater than that of the stand-pipe, a much larger quantity of water at a high pressure is always in readiness. This is of importance in case of fire, and this after all is just when pressure is most needed. The delay in pumping up, when the level of the water has been allowed to fall considerably, is one of the strongest arguments against stand-pipes. However, this disadvantage may be obviated by the use of a device for automatically disconnecting the stand-pipe from the distributing main in cases of emergency, several of which have been invented.

There are many rules for finding the thickness of the plates of which the shell is made.

The following one, which is sometimes used for steam boilers, allows for rivetted joints, and assumes a net strength of 6000 lbs. per sq. inch, and reads :—

"Multiply the diameter in feet by the pressure in lbs., divide the product by 1000, and the quotient will be the thickness in decimals of an inch." This not very explicit rule, however reliable it may be in the case of boilers, does not work very well in the case of stand pipes and tanks, with their extreme range of pressures and proportions. For example, the stand-pipe in Sandusky, Ohio, is 25 feet in diameter and 208 feet high; this rule would make its lower sheets $2\frac{1}{4}$ inches thick, while in reality it has stood for years with a thickness of $\frac{7}{8}$ of an inch. And again, in the case of a stand-pipe 5 feet in diameter, the sheets near the top, when the pressure is only 1 lb., would be $\frac{5}{1000}$ of an inch thick, *i.e.*, thinner than the thinnest tin plate.

The following formula, in which a constant is introduced, is simple and seems fairly reliable :

$$\frac{h \times d}{10000} + .2 = t$$

in which h = head of water in feet, d = diameter of pipe in feet, and

t = thickness of iron in decimals of an inch. The thickness may decrease in half a dozen or more changes until the top is reached, and each successive change can be calculated by the same formula, using the distance of the lowest part from the top of the pipe. The thickness of the bottom may be made the same as that of the sides half way up, unless it is to be laid on some kind of a foundation requiring special strength, as when supported by beams like the floor of a house.

Whatever formula is used, the greatest load which comes upon the lower rings in a stand-pipe is the pressure due to the column of water when the stand-pipe is full; and if they are proportioned to meet this, they will be quite able to bear all other strains. But the *upper* rings, while of a sufficient thickness for the hydrostatic load, may be so light as to collapse under moderate wind pressure, should the water be below the ring, and an extra thickness must be provided to meet this condition.

The ordinary size of sheet used is $5' \times 12'$. The vertical joints should be double-rivetted for at least two-thirds of the height, while the horizontal ones need only be single-rivetted, the strains in them being far less than those in the vertical.

The bottom is usually connected to the shell by an angle iron. The top of the pipe may be trimmed on the outside with a flat iron band or hoop; but trimming on the inside is apt to interfere with ice floating in the stand pipe in winter.

The anchor bolts and foundation should be proportioned in accordance with the assumed wind pressure. It is the practice of a writer in the *Engineering News* to use $1\frac{3}{4}$ inch bolt for each 16 feet of height, with masonry foundation 8 feet deep and stepped out $3\frac{1}{2}$ feet on each side beyond the stand pipe, each bolt passing through a strap lug attached to the lower part of the pipe by six or eight rivets. For example, if the pipe is 160 feet high by 10 feet in diameter, the use of 10 bolts going through a foundation 17 feet in diameter is a good approximation This arrangement of base gives great stability to resist wind pressure.

The best form for a stand pipe is the cylinder, because a tapering one costs more for the same cubic capacity, has less storage capacity at the top where it is most required, weighs more for equal strength, and its shape prevents the ice, which forms in cold weather, from moving up and down with the variations in height of the water, which causes severe strains in the material of the plates. It has been found that the proportions of the lightest tank to hold a certain quantity of water are two in diameter to one in depth.

In calculating the contents in U. S. gallons, the following rule is convenient; also if the quantity measured in this way is assumed to

vary in temperature 10°, it will cover all discrepancy in volume from the results of the most elaborate calculation :—

Let h = height of tank in feet.
" d = diameter " in inches.
" g = capacity " in gallons.

Then $\frac{.17g}{d^2} = h,$

$$\frac{.17g}{h} = d^2$$

$$g = \frac{h \times d^2}{.17}$$

The following description of a stand-pipe lately completed at Malden, Mass., will give some idea of the details of construction :—

Malden is one of the many suburban towns of Boston, Mass., and has a population of about 20,000. Its original situation was in a valley around the base and in the vicinity of an elevation known as Wales Mountain; but within the last few years it has been extending up the slopes of the hill, in consequence of which this newer portion of the town was left without sufficient water pressure in time of fire. The water supply until the present year was taken by gravity from a pond 3 miles distant, and was fairly sufficient for most purposes, while the area covered by the town was confined to the valley. But the demands of the elevated portion of the city for increased pressure made some form of high service necessary, and it was therefore decided in this connection to construct a reservoir or stand-pipe on the top of Wales Mountain. This was evidently the best location for the storage reservoir, being situated almost in the centre of the town and of sufficient height to give the requisite pressure.

The ordinary " core wall and earth embankment " reservoir was out of the question, owing to the character of the hill, which was composed almost entirely of an igneous granite rock, the greater part of which was exposed.

It was therefore decided to construct a stand-pipe or tank of wrought iron, with a capacity of about 1,000,000 gallons, the latter name being in this case more appropriate on account of the dimensions, viz., 75 feet in diameter and 35 feet high.

The foundation for the stand-pipe was constructed on a solid ledge which forms the summit of the hill. Fig. 1, Plate IV., shews a cross section through this ledge with the foundation finished, the original line of the surface being represented by the dotted line.

The exact site having been chosen, it was next laid out, in squares and cross-sectioned, and then a certain elevation was determined upon—200 feet above city datum—as that of the bottom of the stand-pipe when finished, which was such that it left part of the summit above grade and part below. That portion of the rock which was too high was removed by blasting, while the remainder was brought up to grade by first cutting steps in the sloping sides of the rock to get a firm footing, and then building it up with masonry laid in cement mortar.

There was also considerable blasting required in forming the pipe chamber through which the supply main passes into the tank.

This pipe chamber is situated as shown in Fig. 1, and is 10 feet long, 5 feet wide and 6 feet deep. It is roofed over with a 12 inch brick arch through which at the inner end there is a circular opening $2\frac{1}{2}$ ft. in diameter, to allow the supply main to enter the stand-pipe. Across this hole at each side of the main are placed two 5 inch I beams to support the bottom of the tank. The portion of the chamber outside of the foundation is covered with a large piece of North River flagging 5 inches thick, with a manhole 2 feet in diameter cut in the centre and fitted with an iron cover. When the base had been brought to an even grade, a granite underpinning 12 inches wide and 16 inches high was laid around the outside. This underpinning, which has a 3-inch wash-cut, secures the foundation from the effects of the frost and also gives it a finished appearance.

The foundation having now been completed, the next step was the erection, directly over and upon it, of false works three feet high, upon which to put together the bottom of the tank. This bottom is built of plates 10 feet long, 6 feet wide and $\frac{5}{8}$ of an inch thick, rivetted together by a single row of $\frac{3}{4}$ inch rivets spaced $3\frac{1}{4}$ inches apart centre to centre. The plates around the outside were made of a softer metal than the others, to allow of the formation of a 5-inch flange around the entire circumference. To the flange the first row of side plates was rivetted.

The bottom of the tank was put together and the first row of side plates attached on the false works above referred to, so that the next process was to lower it into its position on the foundation.

The specifications required that there should be a four-inch layer of Portland cement mortar (one of fresh ground cement to two of clean sharp sand) over the whole foundation, in order to give the bottom a perfectly uniform bed to rest on. These constituents, after being well mixed, were put in dry, the moisture from the foundation, bottom, etc., being considered sufficient to set it.

The bottom was lowered by means of jacks beginning at the centre and working outwards. As fast as the false works were removed the cement was drawn in in bags and spread in place. When the false works had all been taken away, the outside edge of the tank was lowered on to a number of 6 ″ × 8″ spruce blocks about a foot long, placed at intervals of 10 or 12 feet. The jacks were then removed, leaving the tank resting on these blocks, the bottom being already down, having sagged a foot. After seeing that everything was clear, the blocks were broken to pieces by sledge hammers, letting the bottom perfectly true with the foundation in every way.

The process of construction was now continued, the plates for each course being hoisted into place and fastened with temporary bolts until the rivet holes were all in line, the use of a drift pin not being allowed. The first or lowest course is connected with the flange (the flange being inside) by a triple row of $\frac{7}{8}$ inch rivets spaced $2\frac{1}{2}$ inches apart centre to centre, the rivets in the several rows occurring alternately. The first two courses are made up of plates 6 × 10 feet and $\frac{3}{4}$ of an inch thick, the vertical seams being triple rivetted and the horizontal ones double rivetted. The triple rivetted laps are 5 inches wide and the double rivetted $3\frac{3}{4}$ inches.

The plates of the next two courses are of the same dimensions as those mentioned, except that they are $\frac{1}{2}$ inch thick, and all the seams are double rivetted. The two top courses are composed of plates $5\frac{1}{2}$ ′ × 10′ and $\frac{5}{16}$ of an inch thick, and all the seams are single rivetted with a lap of $2\frac{3}{4}$ inches. All the seams were carefully caulked by hammering or welding the edge of the plate (planed at an angle for the purpose) into the one over which it is lapped. In one of the lower side plates there is an oval-shaped manhole—24″ × 18″—fitted with an iron cover on the inside and proper bolts and yokes on the outside. By means of nuts bearing upon these yokes, the cover is firmly drawn up against a rubber seat, making it tight and secure.

Twenty-eight feet from the bottom, the stand-pipe is encircled by a balcony. It is made up of $2\frac{1}{2}$″ × $2\frac{1}{4}$″ × $\frac{5}{16}$″ angle iron with a floor of hard pine, cut rightways and well oiled, laid radially with the tank, and fastened with $\frac{1}{4}$ inch carriage bolts. The whole is supported on brackets, made of 3″ × 3″ × $\frac{3}{8}$″ angle iron rivetted to the sides of the tank. The balcony is reached by means of a staircase built of angle-iron with cast-iron steps, which is supported on angle-iron brackets bolted to the sides of the tank.

The stand-pipe is covered by a slate roof with twelve sides, supported by 12 iron trusses of the form and dimensions shown in Fig. 2.

Between the trusses the roof is supported by five rafters of channel and angle iron, and across these, 10½ inch centre to centre, are placed the purlins, which are made of 1" × 1½", 6 lb. per yard T iron. The roof is covered with the best of Eastern slate which is fastened to the purlins by "Farquhar's Patent Clasp"—a very neat and effective arrangement for the purpose; it consists of nothing more than a small bolt and a piece of wire bent into a particular shape. (See Fig. 3.)

The roof was designed and built by the Boston Bridge Company, and put in place by them, for the total sum of $5000. The specification required the roof to be able to sustain the following vertical loads. On the purlins 45 lbs. per sloping square foot of roof surface; on the rafter 50 lbs. per sq. ft., etc.; on the trusses 55 lbs. These loads not to strain the iron in tension more than 12,000 lbs. per sq. in., nor in compression more than 10,000 lbs. per sq. inch. The iron used was the best American bridge iron. The trusses are all tied together in the centre by 1 inch iron rods.

The roof is surmounted by a galvanized iron ventilator or cupola of a neat and ornamental design.

When all the iron work had been completed, the inside of the stand-pipe was given three coats of black asphalt varnish, while the outside was painted with the same number of coats of white lead and linseed oil. The pipe has a capacity of 1,180,000 gallons, and the elevation of the water when full is 235 feet above city datum. It was pumped full about the 1st of August last, and proved perfectly tight, there being no sign of any leakage beyond a slight exudation or "sweating" for a short time.

The cost of the foundation was $1500, of the roof $5000, and of the stair $500. The stand-pipe itself was built by the Cunningham Iron Works of Charlestown, Mass.

The total cost of the structure when completed, including that of the foundation, was $22,440. It was built under the direction and according to the specifications of M. M. Tidd, C.E., of Boston, Mass.

From the drawings accompanying this paper Plate IV. has been prepared.

Thursday, 13th February.

JOHN KENNEDY, Vice-President, in the Chair.

Paper No. 38.

THE SCREENING OF SOFT COAL.

By J. S. McLennan, B.A., A. Can. Soc. C.E.

Coal comes from the pit to the surface as the miner has broken it down. He loads into the tubs the lumps and fine coal made by his pick in holing or undermining his shot, or in breaking up the large mass which is tumbled over as its result. In mines where a layer of stone adheres to the top of the seam, he is bound under a penalty to clear this off. But with other foreign matters found in the coal he has no concern. Roughly speaking, few seams are absolutely free from such impurities, and, to bring the coal to its best merchantable condition, these must be removed as far as possible. When this has been done the coal is "run of mine" in the commercial sense. Round coal is that which passes over a screen, the bars of which have between them apertures of $\frac{1}{2}$ to $\frac{3}{4}$ of an inch. Slack is the coal which falls through these apertures, and it is often passed through a secondary screen and divided into nut and duff.

The desiderata in screening are therefore:—

I. Effective separation of sizes; so that slack may not be carried among the lumps into the round coal, or so that, in avoiding this by wide openings between the bars, too large coal may not pass into the slack, a consideration of some importance in shipping slack to the United States, where an excessive size would render the cargo liable to a higher rate of duty.

II. An opportunity for the removal of mechanical impurities as stone or pyrites, which occur in some mines as "balls," or elsewhere in laminations so thickly grouped, as to be easily visible.

III. The minimum of breakage in the transit, from the pit tub to the railway car, the vertical distance between the levels of which is from 15 to 25 feet.

The ordinary method of screening is by a fixed screen about 20 feet long and 6 feet wide, inclined at an angle of about 25°. The effective screening surface is reduced in many cases, by the use of cast-iron

bars about $\frac{3}{4}$ inch thick. The tub is commonly provided with an end door, and, when run on a tumbling cage, it is tipped into contact with the upper end of the screen. The door is opened automatically or by the attendant, and the coal slides down the screen. As there are no means of regulating its speed, it very imperfectly fulfils all the conditions of screening coal, except rapidity, as it is obvious that coal can be sent down it as rapidly as tubs can be tipped; but it is not separated effectively, no opportunity for picking is given, and the breakage of the lump coal and also of railway cars is excessive.

The method of screening adopted by Mr. Poole, at the Acadia Colliery in Pictou county, is effective and economical. He describes it as follows:—

Coal is drawn from the mine up an incline of 24° to 28° in boxes holding a ton each. The boxes have end doors, and are run forward on the bank head, 28 feet above the main railway, to a rocker. The loaded box tilts up, the door is released, and the coal slides out on to a dead plate at the head of the screens.

The dead plate, 3 ft. wide, dips at an angle of 40°. From its ower edge proceed two sets of bars which we may call A and B. A is 5 ft. long, and is made of 2 in. bars placed 6 in. apart. It inclines at an angle of 12°. To the far end is hinged an apron 12 ft. long, ordinarily lying at the same inclination. The free end of the apron is sustained by a counter weight. When the weight is down and the apron up, the passage over its upper surface is closed by a fixed stop suspended from above, at a point two-thirds of the distance from the near end.

The "B" set of screen bars are 12 ft. long, 1 in. sq. iron and $\frac{3}{4}$ in. apart; they start from the dead plate under the heavy bars at an inclination of 45°, being continued at a lessening inclination until an angle of 21° is reached, at which inclination the screen then remains. A hopper under these bars collects the "slack" coal that has fallen through, at the lower end of this screen; a short fixed screen 2 ft. 6 in. long with $2\frac{1}{2}$ in. openings separates out the "stove" size. Thence onward the screen is lined with perforated plates, and terminates in a counterbalanced apron 4 ft. wide, which, as required, checks the flow of coal over the screen and enables stony coal, etc., to be seen and removed; or entirely stops the flow, and allows coal to accumulate while cars below are being shifted.

The object of the coarse screen A is to separate out "furnace" coal, and the separation of very large lumps from the run of mine enables a more thorough screening of the remainder to be effected. The fur-

nace coal slides forward on the apron and collects against the fixed stop. When the apron is full, the screenman lifts a brake from the counterbalance, the apron then descends until the point rests on the regular screen; and while it is descending, the coal upon it is slowly sliding forward, and thence passes quietly on without a drop into the car below.

The slack collected in the hopper under the screen drops into a well, from which it is elevated to the level of the bank head, and dropped into a revolving screen 12 ft. long by 4 ft. diameter, covered with wire cloth of $\frac{3}{8}$ in. mesh. This screen separates the slack into "nut" and "culm."

The above will make clear the arrangement at Westville; at the other pits the ordinary screen is in use.

The arrangements at "Acadia," which are thoroughly effective, require a high bank head to give space for the screens, and thus were not available as models, when the writer decided to change the screens he found in place at the International mines. Notwithstanding Mr. Poole's kind assistance, some other device had to be used, which could be placed in a bank head only 21 feet high. No other screens are in use in Nova Scotia, and the apparatus known as Riggs Patent Curved Balance Screen was imported from England. It is shown in Plate V, Figs. 1 and 2, and consists in the tipping cage shown in Fig. 2, in the position in which the loaded tub is pushed into it. The tub is retained in position by angle irons, which project beyond and slightly above its edges. The lever shown in the sketch which operates the hand brake is partially released, and the whole cage turns over slowly until it reaches the position shown in Fig. 1; the coal slides out of the tub on the screen, and by gravity the cage assumes its former position. The tubs are "solid," that is without end doors, and thus save a good deal in repairs, the doors being the parts most liable to get out of order.

The screen is 6 ft. wide and 11 ft. long from the top to the journal shaft which supports it, and thence to the mouth 13 ft. in length. To the journal shaft is keyed a large brake wheel, the band brake on which is controlled by a bell crank lever indicated in both sketches. The angle of inclination of the upper part is 25°, and of the lower 8°. The momentum of the coal from the tub carries it forward to the lower part of the screen, where it lies until it is inspected, and, if necessary, cleaned; then, on the release of the brake, its weight causes the screen to tilt downwards to the position shown in Fig. 2, until the coal slides gently into the car. When the weight is removed the screen returns to its former position.

It will be seen that, in giving a chance for cleaning the coal and

saving of breakage, it is perfect, and very good for separation of sizes. It is, however, slow, and by requiring more screens is thus more expensive for a given output than the old type. Its first cost is high, and, consequently, a modification, suggested by Mr. John Johnston, the underground manager, has been adopted. This is shown in Figs. 3 and 4. The screen is the same length, but is 7 ft. 6 in. wide. The upper part is fixed at an angle of 28°.

The lower part rests on a journal at X, and is supported by a counter-weight W, controlled by a brake B around which the connecting wire rope passes. The Rigg's cage is used with this screen. When the coal is ready to be deposited in the cage, the brake is released, and the point of the screen descends as in Fig. 4. When the coal is off, the counter-weight brings the screen back into the position in Fig. 3. In Figs. 1 and 2 is shown the box in which slack is caught and deposited in a car. In the other is indicated at E an endless chain conveyor, which carries it to an elevator to the subsidiary screen on the bank head, where the nut coal is taken out.

While this system is more costly than the normal type, its efficiency more than compensates for the cost in giving a cleaner and larger coal than was formerly obtained.

The Old Sydney and Victoria Mines employ an apparatus known as the Billy Fairplay which Mr. Brown, the manager, has kindly described for this paper. He says:—

The "Billy Fairplay" system is in use at the Sydney mines of the General Mining Association, Limited.

By this method the coal is not riddled in the pit by the colliers, but is filled by them just as it is cut, into the tubs or boxes, the large and small or slack coal all together. On arrival at the surface, the tub of coal is weighed, and the gross weight of the coal it contains is recorded. It is then dumped into the screens; the screened large coal passes over the bars of the screen into the cars, and the slack coal passes through the spaces between the bars of the screen into a hopper.

From this hopper the slack coal falls into a tray which hangs suspended on pivots from an indicating dial overhead. When all the slack from a tub of coal has thus gone into the tray, its weight is ascertained by the dial, and the tray is then capsized by a string pulled by a small boy stationed at the screen for the purpose, and the empty tray resumes its original position ready for the next tub of coal.

The gross weight of the coal that was in the tub is placed to the credit of the collier who sent it up, and the weight of slack that has been screened from that tub is placed to his debit; he is paid a certain price per ton, only on the difference, that is, the screened large coal.

The advantages of this system are, that the colliers are saved the labour of riddling their coal by hand, and that it discriminates in favour of the skilful workman, who hews his coal with a view to make as little slack as possible, and gives him, as he deserves, better pay than the careless miner, who breaks up an undue proportion of the coal which he produces.

The slack coal is emptied by the capsized tray into a small tub. This tub, when full, is drawn up a steep incline by means of a small engine and wire rope, and when arriving at the top it automatically empties itself.

The slack coal from the tub falls upon an oscillating screen composed of wire netting of half inch square mesh, which separates it into nut and duff, each of which passes through a shute into a car of its own on the railroad below. If slack coal is at any time desired in the cars instead of nut and duff, then the wire netting screen is not used.

The Billy Fairplay system is largely used in Wales and in the north of England.

It may be noted that, while the "Billy Fairplay" is a very valuable incentive to the miner to reduce the slack to a minimum, the practice of riddling coal in the pit to which Mr. Brown refers has been abandoned by all but one or two mines in Cape Breton and Nova Scotia. The English practice is very elaborate at the best collieries. Screens having bars with reciprocal motion carrying the coal along, circular screens revolving horizontally, so that different bands of coal can be sorted into different cars, are in use, all of them elaborately explained in Percy's Mechanical Engineering of Collieries. In the Pittsburg region, the screening appliances are good. In many cases a very high bank head allows enough assorting of the different sizes through a succession of screens into different cars; but while it may not be true of other departments of the industry, the best practice in screening in this province is abreast of the times.

From the drawings accompanying this paper Plate V has been prepared.

DISCUSSION.

Mr. McLennan said that only the two mines mentioned of the General Mining Association paid the miners for large coal; at all the other mines the colliers were paid per ton of run of mine, and the coal was screened as the company chose. Mr. McLennan.

Mr. H. Wallis said that he had listened to Mr. McLennan's paper with much interest. The process of screening described was one which would, no doubt, turn out coal in excellent condition. At the same time he was not greatly impressed, having regard to the commercial value of coal at long distances from the mines, with the necessity of screening it at all. The Grand Trunk Railway Company used run of mine coal only, after an extended experience with the various grades of lump and nut, the reason being that the expenditure for screening, some 20 cts., added to the cost per ton, did not ensure the delivery of the coal, after much handling and long haulage, in the condition expected. The company paid for lump coal and received apparently the run of the mines, the grade having been lowered in the manner named, but the difference was not so apparent under the present system of purchasing. He would, however, prefer the lump coal if it could be delivered as contracted for. There was a difference of 8 or 10 per cent. in its favor, varying as a rule in accordance with the hardness of the coal. He was aware that it ought to be cheaper to the consumer to use long distance coal as lump rather than of a lower grade, and so it would but for the objections mentioned. It was true that recent improvement in locomotive practice, including what are known as extended smoke boxes, together with largely increased grate surface and the introduction of the compound principle, had rendered possible a steady if softer exhaust, and therefore reduced the tearing action on the fire to an extent which had in some cases permitted of good results having been obtained from slack. He desired to ask what percentage of culm and slack was left over after screening. Mr. Wallis.

Mr. Dodwell enquired whether the damage which the coal sustained in transit was due entirely to handling or in part to disinte- Mr. Dodwell.

gration, and also whether the author had had any experience with lime cartridges and did he coke the slack. In 1870 or 1871 he spent a month or two at the Albion Mines, and the slack coal was then looked upon as a nuisance. The loading ground was ballasted with it, and it struck him as being singular that it should be considered valueless when it might have been used for coking or making briquettes.

Mr. St. George. Mr. St. George said he thought a screen necessary as an incentive to good mining. He considered clean coal necessary to good steaming in stationary boilers, particularly with forced draught, and the experience of engineers on the ocean steamers was that their speed had been increased by the cleaner condition of the coal. He was aware that in Virginia, especially West Virginia, in the Alleghany Range, they coked all the coal now. He would like to know how it would answer to ship coal to a large market and screen it there. In Belgium the practice was to cover the slack coal with earth and to plant it with trees.

Mr. Wanklyn. Mr. F. L. Wanklyn enquired what experience the author had in the use of powder, also had he used hydraulic rams with long buckets for breaking down the coal.

He thought it would suit them better to simply clean the coal instead of separating it into different sizes. There seemed to be a larger percentage of dirt and shale in the Lower Province coal than in that from the United States.

He would like to know the difference in price at the pit's mouth between lump and run of mines coal, and if it is the custom to dress the cars conveying run of mine coal, that is, to place the lumps at the top? He had noticed cars apparently loaded in this way.

He believed that briquettes were used in Europe when coal was carried long distances, because in this form it did not deteriorate so much from exposure to the atmosphere, and they could be more readily slacked, although owing to the pitch used in their manufacture, such coal gave off more smoke in combustion. The system adopted in England of firing factory boilers by mechanical means had rendered possible the burning of small coal with satisfactory results. The regularity with which the furnaces were fed, in relation to the quantity of air supplied, prevented loss through the tubes, and the percentage of ash was inconsiderable.

Mr. John Kennedy enquired whether coal could be cleaned without screening so as to save the cost of as well as the loss by screening. Mr. Kennedy.

In buying cargoes of coal it often appeared to him to be all slack, and at times he found it hard to persuade himself that it had been screened at all. He supposed that the better draught obtained in all sorts of boilers, especially on board steamers, and to some extent in locomotives, enabled them to use more slack or run of mine coal than formerly. Ten years ago enormous quantities of Scotch coal were used in Montreal, because it was thought that nothing else would give satisfaction, until the price rose so high that steam users had to purchase Lower Province coal, and now scarcely any Scotch coal came into the market.

Mr. Rhodes said he would be glad to have some information as to the manufacture of slack into briquettes. Large supplies of these were manufactured at the Taff Vale collieries in Wales, and shipped to Continental railways. They were made from the pure washing of the slack coal pressed into shape with hot pitch. There was a large and increasing trade done in these briquettes, principally with French railways. Mr. Rhodes.

Mr. McLennan remarked that Mr. Wallis had spoken from the standpoint of the consumer, and what he had said was undoubtedly correct from that as well as from his own standpoint. They endeavoured to persuade their customers to use "run of mine" coal, especially in markets reached by vessels, on account of the damage to the coal caused by dropping into the vessels and afterwards from the vessels into the dumps. If the handling could be reduced so that coal could be simply cleaned and sold as run of mine, it would be an advantage to everybody concerned except householders. His company had not sold to the Grand Trunk Railway Co. for a long time past, but he did not think that company had ever received from them unscreened coal. He remembered distinctly the impression made on him by the appearance of a cargo of coal in Montreal which had been loaded in Cape Breton. It was absolutely unrecognisable, and if he had not known the ship, he would have doubted its being the same coal that he had seen in Cape Breton five or six days previously, the destruction in handling had been so great. Mr. McLennan.

With reference to the percentage of culm and slack coal, it averaged from 25 to 30 per cent. over $\frac{5}{8}$ inch apertures. At one mine

it was as much as 35 per cent. Mr. Routledge claimed to get 18 per cent. only but he riddled in the pit at that time. The average might be taken as from 22 to 28 per cent. It depended to some extent on whether the screens were double or not.

Their miners were paid by the ton on the run of the mine which was supposed to be cleaned from stone, slate and roof. They could do this in their mine where there was only one band in it, and that about one inch thick. The lump was cleaned out and a proportion had to be afterwards broken in order to get out the slate before shipment. When the coal was riddled in the mine the refuse was left there. In some mines this practice would be a source of danger. If there was a demand for slack it would be taken out by bags. It was thought that the "Billy fair-play" system, mentioned by Mr. Brown, would make the miners more careful, but when they found that the slack for which they were not paid was being sold, objection was raised to the system.

In reply to Mr. Dodwell, the damage to the coal was not so much due to disintegration, which did not take place until some months afterwards. Coal that had been badly mined or shaken with powder would break sooner, but no doubt all coals commenced to disintegrate slowly from the time they were mined. His experience with lime cartridges had not been satisfactory. One man lost an eye through some which had been sent out to the Sydney Mines to try. With regard to the slack they coked merely what was required for local purposes. Cape Breton coal coked tolerably well, but was a little high in sulphur for iron working.

As to the necessity for screening as an incentive to good mining, it was customary to pay for each ton of coal sent up if it were reasonably clean. It would hardly pay to screen coal at the point of delivery, which would cause double handling and therefore increase the cost, but it might be done if the market at that point were large enough for pick coal.

Replying to Mr. Wanklyn, the hydraulic rams had not been tried in Canada, and were only useful when the coal made a clear parting from the roof. If the roof parted badly the coal had to be picked over. It depended upon the strata next the roof. He had thought sometimes of obtaining a few wedges to try. In every seam were one or more bands. He believed that in the case of the Pittsburg coal—perhaps the cleanest coal in the United States—the band was very much broken up. They mined out six feet and actually sent to lump four to four and a half feet, while the rest of the coal,

between six and seven feet in height, was thrown away. The difference between the value of lump and run of mine coal at the pit's mouth would probably be twenty cents or a little over, it would depend upon the price obtained for slack. In the Newfoundland market the domestic consumers wanted lump coal entirely. He did not think it was usual to dress coal cars in the manner suggested.

Referring to Mr. Kennedy's remarks, the cost of cleaning coal included the screening. In reality considerable labour was expended beyond that actually engaged in screening. The slack was worth from 50 to 60 cents a ton.

It was quite as painful for the coal owner as for the purchaser to see the condition in which the coal very often arrived at ports of delivery. Shippers took a pride in sending it away in good condition, and the damage which took place in transit was most discouraging to them. Vessels to be economically worked should be about twenty feet deep in the hold, and it would be in the interest of the consumer if the system of discharging could be improved. The method of hoisting a tub of coal by a whip and turning it over into a car caused more breakage than the loading of the vessel.

With reference to the manufacture of briquettes, at the Gowrie Mines they had Yeadon's apparatus, and they made tolerably good bricks, but the practice did not seem to be much favoured. Moreover, they had not any great excess of slack in Cape Breton or Nova Scotia, and there was not the same pressure now as years ago to get rid of it. He had been surprised to see how small was the export of bricks at Cardiff; the trade did not seem to have kept pace at all with the coal trade from that city, although he was aware that the French railways were rather large consumers.

Referring to the burning of slack coal, there was, as had been remarked by Mr. Wanklyn, some difficulty with a high forced draught, much of the coal would, under such conditions, pass through the tubes and up the smoke stack unburnt. One of their steamers carrying coal to Montreal some years ago and burning slack ran under such conditions with an excessive consumption, he thought, of about 25 per cent. He believed, however, that quite a number of colliers were running on the east coast with slack coal entirely, and with a different arrangement of grate; they could probably do the same.

The maximum evaporative results would probably be obtained from the use of nut coal. Slack was more likely to heat spontaneously, but it would part with the volatile carbons more readily even although there might be no actual heating.

Mr. Leonard. Mr. R. W. Leonard said that in Spring Hill, all stone or other impurities must be separated in the pit by the loader employed by the coal cutters, and boxes of dirty coal are "docked" at the bank head, *i.e.*, the miner is not paid for them.

The form of the bars has much to do with the successful screening of soft coal. Cast-iron bars are rough, and are apt to cause much trouble in cold weather by freezing up; square bars set on edge are very well adapted for the work, but it is necessary to clean them continually with a hoe, as certain sized pieces will stick between them. Flat top bars $\frac{3}{4}''$ wide on top, $\frac{1}{4}''$ at bottom, and $1\frac{1}{2}''$ deep are not so subject to this trouble, but do not screen as efficiently, unless the screen is made in two sections with bars in second section opposite space in first part.

The "ordinary method" described by Mr. McLennan is used in screening in Spring Hill, and is found to suit our requirements very well. Two of our bank heads are too low (18 ft. and 22 ft.) to adopt the admirable system described by Mr. Poole.

The output of these mines is very large, and 1300 boxes of 1650 lbs. have been passed over two screens in ten hours. The screens are six feet wide, and are fixed at an angle of about thirty degrees. The bars are ten feet long, of one-inch square iron set on edge, and spaced three-quarters of an inch apart. The speed of the coal sliding over the bars is regulated by a stop door above the screen bars, hinged at the top, and held by a lever by which the door can be opened as much as is necessary to run the coal over the bars at the required speed. By keeping the shute full above the stop door, the coal is not broken much by being stopped in that manner. Below the bars is a long apron running out to a flat angle on which the coal rests, where it is thoroughly picked by men handling it over with hoes. With careful work Spring Hill coal can be well screened without much breakage, although it is one of the tenderest coals in the Province. The slack is run into cars, and is then taken to a large revolving screen if required to be further separated into nut and culm.

This screen was erected last year and has a capacity of over 400 tons in ten hours (it has screened 516 tons in that time); it is 20 ft. long and 5 ft. in diameter. The coal is hoisted by an endless chain of buckets 40 ft. from a hopper under the track, and may be separated into

four different sizes if required. The different sizes drop into separate bins, and are thence run into cars as required. The cost of screening at the Rotary is about 6 cts. per ton, including shunting of cars.

The modified Rigg's system of screening finally adopted by Mr. McLennan is essentially identical with a system in common use at the collieries on the Kanawha River, West Virginia.

In that district the Mount Carbon Coal Co. has a most ingenious "coal transfer" or wharf for loading their coal (which is very easily broken) into barges, at the greatly varying heights of water in the river. This wharf, which is very cheaply and substantially constructed, has a capacity, it is stated, of about 400 tons per hour. It breaks the coal less than any other system the writer has seen, and is a very cheap one for even small shipments. It is fully described in the Transactions of the American Institute of Mining Engineers, 1888, but a short description of it will not be out of place here. It is a simple application of a flexible steel belt 4 ft. wide, with 6 inch flanges, and of the required length between sprocket wheels to suit different heights of vessel or water without being so steep as to allow the coal to move on it. The motive power is a small stationary engine, and the belt virtually draws the coal from the open hopper of the car and carries it to the vessel. The outer end of the belt is raised or lowered (being pivoted at the inner sprocket wheel) to suit varying stages of the water. This system is being rapidly adopted in the "New South," where coal is required to be handled without breakage. The Cumberland Railway and Coal Company are preparing to erect a similar wharf at Pugwash, for loading into all classes of vessels for the St. Lawrence trade.

Mr. E. Gilpin said that in Nova Scotia for many years the distinction between round and slack coal was an arbitrary one. The screens at all, or nearly all, the collieries being made with bars $\frac{3}{4}$ of an inch apart, in order that the requirements of the royalty clauses of the Mines Act might be most readily complied with. The law required a payment of 6d (9.7 cents) per ton of 2240 lbs. on all unscreened or round coal, *i.e.*, coal that had not passed between the bars of a screen placed $\frac{3}{4}$ of an inch apart. In the earlier days also nothing but lump coal was considered marketable for general purposes. In the Block House pit, Cape Breton, gas coal was riddled in the pit through riddles having $\frac{1}{2}$ inch meshes, and passed without the formal screening direct to the vessel, the saving in time and expense compensating for the increased amount of royalty paid. At other Cape Breton mines

Mr. Gilpin.

riddled coal was banked out during the winter, and when screened in the spring was found to have made nearly as much more slack. The result of the adaptation to market purposes of the size of $\frac{3}{4}$ inch, as distinguishing slack from round coal, has been that hundreds of thousands of tons of nut coal, equal to round for nearly every purpose, have been thrown away and irrevocably lost.

His experience has been that at Nova Scotia collieries, under ordinary circumstances, steam can be as quickly raised and as readily maintained by slack coal as by the more costly fuel. The Provincial Insane Asylum, under the charge of the Works and Mines Department, has for a number of years used culm from Pictou for boilers, for pumping and steam heating, with the most satisfactory results. Several plans have been tried with more or less success for screening, in addition to those referred to by Mr. McLennan. Doors are put across the screens, so that the coal can pass over them at the speed and in the amounts desired by the screeners. A flat plate at the foot of the screens often receives the coal which undergoes a final cleaning, and then the plate, turning by a lever, falls into the coal car.

Underneath the round coal screen, attempts have been made to separate the nut and culm by means of square-meshed iron wire screens having a lateral shaking motion. At Spring Hill a separation into three classes of small coal has been satisfactorily effected by a revolving screen taking the coal from an endless bucket rope. Great trouble is experienced in screening wet or damp coal, especially when the operation is performed while the temperature is several degrees below freezing point. The shape of the small pieces into which the coal of any particular seam breaks is also an item to be observed, for with some coals longitudinal screens will take out more slack than square-meshed screens of relatively greater area.

He believes that, at the present stage in the preparation and use of coal, a good nut coal gives the greatest satisfaction to buyers for all steam and domestic purposes. The great object of coal producers is the introduction of a satisfactory system of burning slack coal. At the mine the object should be to ship all the coal that is raised for the market as well cleaned as possible. At the market the lumps could be separated down, say, to stove size, and sold for domestic grates, etc. Then the resulting coal could be separated into nut for ranges, small stoves, etc., and pea and culm for factories, etc. If this could be done the problem of screening would be immensely simplified, and the sale of the small coal, now thrown away, would represent, in many cases, a handsome profit, and lessen the inroads on the solid coal reserves of the mines.

Mr. H. S. Poole said that Mr. McLennan almost implied that the credit of one of the designs he described is due to him, but that he cannot claim anything more than the simplification of a few details, *e. g.*, the removal from the outer end of the A screen apron of a door, which on descending is opened by a catch striking a projection. As contrived the latch did not always close, and the improvement consisted in substituting and so adjusting a fixed stop over the apron, that the increased distance for the coal to slide from the stop outwards, allowed sufficient time for the apron to descend and come in contact with the main screen before the released coal could pass over the end. Another minor detail was in substituting curved bars, at the bottom of the receiving dead plate, for straight bars which were liable to be choked by fragments of coal falling on them vertically and wedging between them. And yet again, by controlling the movement of the aprons by friction merely instead of by rack and pinion. Mr. Poole.

The objects of the arrangements described are, as Mr. McLennan says, to size the coal and separate the good from the unsaleable bone coal and stony shale, etc.; and yet the more complicated must appear very simple to any one familiar with the elaborate structures and appliances known as "breakers" in the anthracite region of Pennsylvania, erected for the same purposes. The anthracite being hard withstands the excessive handling necessary to effect the perfect sizing, and justifies the great expenditure incurred in its preparation for market, while the friable nature of most of the varieties of bituminous coal does not permit of the same treatment being extended to them. Nor would careful sizing be of use in any variety that agglutinated under the boiler, and required after this change has taken place the use of the slice to open up the fires.

It may even be questioned whether, in some cases, it is not useless to extract the small coal and dust made in mining and in handling in the pit, since the coarser portion separated by screening is immediately after exposed to still greater abrasion and pulverization by falling, first some 5 or 6 feet into wagons or cars, and from them into the holds of ships, dropping, it may be, 20 or even 30 feet, shovelled over by the trimmers, shovelled into tubs at the port of discharge, dumped into carts, thence into heaps and the subsequent handling familiar to consumers. Those varieties of soft coal, however, which do not possess the property of caking under heat, and are compact, and which are in demand for grate purposes, may justify greater care in preparation. With ordinary soft coal it may be doubted whether screening beyond so much of the process as consists in picking out the mixed stone and inferior coal

is worth the cost, at least when the coal is subsequently to be exposed to several rough handlings before it reaches the consumer.

To clean the coal more thoroughly than the ordinary screen permits of, mined coals are in some localities crushed and washed, the separation being effected by a pulsating upward current. Or the cleaning is attained by hand picking from tables, either circular, which are made to slowly rotate, or in the form of continuous bands which slowly pass before the pickers.

Mr. Routledge. Mr. Routledge said that from what he has seen of the Billy Fairplay system of screening coals, adopted at Sydney mines, he believes it is the most perfect and honest system for lessening the quantity of slack in working coal which has yet been adopted. The employer pays only for large merchantable coal; the honest and careful miner, by keeping his working low, sheaving it narrow, and studying the proper application and quantity of powder to use, makes considerably more large coal than his careless fellow-workman, and, what is more, the less powder used the more merchantable will coal be delivered at its destination. His knowledge of Billy Fairplay screening goes back for a period of perhaps 28 years, when he saw it first adopted by the present Sir George Elliott at the old Durham collieries in England.

Paper No. 39.

THE MANUFACTURE OF NATURAL CEMENT,

As carried on at the Napanee Mills, Ontario.

By M. J. Butler, M.Can.Soc.C.E.

The Geological Report of the State of New York, 1839, contains an analysis of "Manlius Hydraulic Limestone," stating at the same time: "This stone belongs to the same bed which yields the hydraulic cement obtained near Kingston, Upper Canada." As the only bed of hydraulic limestone found near Kingston is the one at Napanee Mills, there can be no doubt but that it is the one referred to.

It was not, however, until the year 1867 that anything was done towards working the bed, when Mr. H. M. Wright, a lumber merchant, acquired the quarry and had one or two kilns built at the quarry site. The mill for grinding the stone and the cooperage works for the manufacture of the barrels were built at Napanee, six miles distant, where convenient facilities for shipping by boat or rail were to be had, the burnt rock being teamed from the quarry to the mill. Messrs. Wright & Co. produced a fairly good quality of cement, supplying the local demand for a cement for cellar floors, cisterns, dams, etc.; they sold out to George Lasher & Co. in 1874, who carried on the cement and lime business for six years.

In 1880 the Napanee Cement Co. (Lmtd.) was incorporated, buying the mill and cooperage works at Napanee, and arranging with Mr. Lasher to supply the burnt rock to the mill at a stated price per ton. This arrangement proved very unsatisfactory to the Cement Co. In 1883 the cement was so very bad, that it was felt that something had to be done to improve the quality.

The writer was requested by the manager to make an examination of the quarry, mill, method of burning, grinding, etc. On examination it was found that the stripping (consisting chiefly of a loose shale) and all other rock, just as it came handy, without regard to size, quality or anything else, was alike dumped into the kilns to be burned for

about 24 hours. At the mill the grinding was loosely and carelessly done, one burrstone alone turning out 130 barrels per day.

A report was made setting forth the facts and advising a careful test of each layer in the quarry by itself; some to be underburnt, some to the point of vitrification, some intermediately. Attention was particularly requested to getting the grinding as fine as possible so as to retain not more than ten per cent. on a 2,500 mesh. The purchase of a testing machine was advised. It was thought that in this way the best cement might be had that the quarry was capable of producing. Some time in 1884 the manager died; after which the company was re-organized. A new manager of works was secured, and the work of real improvement was energetically taken in hand, and is still being carried on.

In 1886, owing to the construction of the Napanee, Tamworth and Quebec Railway, which passes close to the quarry, it was thought best to build a new mill at the quarry site. Before doing so, however, the Cement Co. had a series of careful and thorough tests of every layer in the quarry made by an expert in the cement business from the United States; his report advised the using of certain layers aggregating some 5½ feet in depth.

The mill is built of stone 40 × 80 feet, three stories in height with an engine and boiler room 40 × 40 feet, also of stone, one story in height, containing an engine of 40 H. P. and two horizontal tubular boilers. South of the main building and 70 feet distant is the stave preparing mill 30 × 80 feet, built of brick. One hundred feet to the east of the main building is the barrel factory 30 ft. by 50 ft., also of brick. The kilns, of which there are three, lie about 200 ft. north of the main building. They are of the continuous burning type, with two doors for firing purposes and one door for withdrawing the charge.

Process of Manufacture:—The rock is broken into pieces of tolerably uniform sizes, averaging about $\frac{1}{10}$ to $\frac{1}{15}$ of a cubic foot each, loaded into carts, hauled to the top of the kilns and dumped into them. There are three continuous kilns fired on two sides; each kiln holding sufficient rock to make about 150 barrels of cement. The charge is withdrawn about every eight hours, depending somewhat on the weather, the foreman and attendant judging from the appearance of the stone the sufficiency of the burning. It requires about half a cord of soft wood to each ton of cement. As fast as the charge is withdrawn at the base of the kiln, it is loaded into an iron car, and hauled by a wire rope up an incline to the third floor of the building. Here it is dumped into a conical box which feeds by gravity into a rock

breaker, and slowly tumbles down to the second floor where it reaches the grinders, about the size of beans. The grinders are the ordinary French burrstones. It is then ground and passed to bolters that are at present 1,600 meshes to the square inch. A finer bolting cloth 2,500 meshes was tried, but was found to clog with the finer particles attaching themselves to the wire. The residue from the bolters is returned to the stones and reground. Numerous tests show that a 2,500 mesh standard sieve will retain barely 10 per cent. After leaving the grinders the cement drops on the first floor, where it is allowed to cool on an average for about two weeks before being barrelled. A series of tests are made from each burning, the procedure in preparing the samples being that recommended by the Committee on cement testing of the American Society of Civil Engineers, the object of the tests being to insure a uniform article.

For convenience of reference and comparison tables of analysis and strength are appended, see pages 102 and 103.

It is not quite such a simple a matter as it appears to prepare briquettes properly for the testing machine. To begin with, the quantity of water used exercises a most important influence, the mortar should be very stiff and be firmly pressed into the mould so as to exclude all air, the operations should be performed quickly, the sample should rest on an impervious plate, glass being probably as good as anything. When the mould is filled, it should be struck off evenly with a trowel, and be left quietly for a short time before attempting to remove the sample from the mould, the slightest disturbance at this stage materially interfering with the proper setting of the briquette. After the sample has set in air, usually one hour being required, it should then be carefully removed from the mould and placed in water, where it should remain until the expiration of the time fixed for breaking.

Once it is placed in the testing machine the load should be applied steadily, quietly, and without jerking up to the breaking limit. Although every care may be exercised in the preparation and manipulation of the samples under test, it will be found that they do not break with uniformity, and it is only by taking the average of a number of samples that anything like a correct result can be arrived at.

Having secured a high tensile strength, as evidenced by the testing machine, the question is, have we a cement that is going to prove itself reliable when subjected to the test of time and the elements? Is there any connection between high tensile strength and good reliable wearing properties? Have the cements that show a high tensile strength proved themselves better under use than the natural cements? Is it not a fact

that the cements which give such a high tensile strength grow brittle with age, and crack and peel off? Witness the cement walks wherever laid, the pointing in any old bridge with the higher testing Portland cements, they will be found full of cracks and scales which can be readily picked off. Although it is very hard, it is brittle, whereas when we come to examine any old work laid up with the natural cements, we rarely find cracks or other signs of disintegration. The variety and extent of the works in existence, built entirely with the natural cements, show their good lasting qualities; witness the Erie Canal, the high bridge on the Croton Aqueduct, and innumerable other works of great magnitude. The writer has used in one season over 10,000 barrels of natural cement from Louisville, Milwaukee and Utica, on foundations in caissons, on well work and in other trying situations without an instance of failure.

At Napanee Mills, the Napanee Paper Co., Limited, put in some three or four tanks of large size, and lined them with the Napanee cement, about ten or twelve years ago, which are perfectly water-tight, the cement having set as hard as limestone rock. At Gananoque the dams and canals of the Gananoque Water Power Co. are all grouted with Napanee cement, some of it having been in use eight or nine years.

In 1883 the writer was present at the tearing down of an old head gate which had partially rotted out, and it became necessary to cut away some posts that had been grouted in. It actually took two good men one day to pick out a post 8″ × 8″ × 7 feet, showing how hard the cement had become. These dams are all water-tight, and the cement is very hard.

At Deseronto, about five years ago, the foundations for a heavy gasometer, requiring to be perfectly water-tight, were, with much misgiving on the part of the superintendent, put in with a concrete composed of two parts sand to one of Napanee cement and three parts broken limestone. Not one cent has ever been expended for repairs, and the concrete is now in first-class order without a crack. On the Grand Trunk Railway bridges, on the canals and other public works of the Government, many thousand barrels have been used, all giving great satisfaction. If too much water or sand is used the mortar will of course be weakened, but when such a record as the above can be shewn from the old cement, there is no doubt but that the cement now being turned out is a first rate reliable natural cement, as good as can be ordinarily secured in any of the quarries in use.

E. J. De Smedt, chemist to the District of Columbia, U. S., says: "A limestone such as dolomite, containing 46 per cent. of magnesia, has been

pronounced unfit for making good cement; but when the percentage of magnesia is not too large, it becomes in time just as hard as a cement containing no magnesia, with this difference, that it is somewhat slow in setting. In sea water containing magnesia such cement should be preferred, for the reason that it does not disintegrate in that water."

TABLE OF ANALYSIS OF VARIOUS NATURAL AND ARTIFICIAL CEMENTS.

Name of Brand. By whom analyzed.	Akron, N.Y. E. C. Boynton.	Buffalo, N.Y. E. F. Cox.	Milwaukee, Wis. E. F. Cox.	Utica, N.Y. G. Bode.	Louisville. E. F. Cox.	Fayettville. E. F. Cox.	Rosendale. E. C. Boynton.	A Perfect Cement.
Silicic Acid	54 77	32 86	28 11	35 43	20 66	18 22	43 11	32 00
Alumina	6 42	8 38	27 62	9 92	27 11	26 76	3 64	8 00
Lime	29 64	52 60	37 18	33 67	50 52	51 99	40 09	54 00
Magnesia	9 17	6 16	7 09	20 98	1 71	3 03	13 16	6 00
Total.	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00

Name of Brand. By whom analyzed.	An Eng. Portland. Ext'd. from Henry	A good Portland. Reid's Treatise on	A Ger. Portland. Portla'd Cement.	Manlius. Dr. Manlius Smith	Napanee. of Syracuse, N.Y.
Lime Ca.O	56 68	60 05	58 03	45 00	39 73
Magnesia Mg.O	0 57	1 17	2 93	18 55	18 02
Oxide of Iron $Fe^2 O^3$	.....	.....	11 30	11 97	10 50
Alumina $Al^2 O^3$	7 74	10 84			
Silicia Si O^2	22 74	24 31	21 11	19 60	26 35
Alkali Na Ho K.Ho	0 63	1 54	0 71	Trace.	.....
Sulphate of Lime So_4 Ca	1 66	.....	0 51	2 04	0.935
Carbonic Acid Co^2	3 50	.....	0 83	2 70	2 95
Undissolved Residue	0 53	.....	0 49	.....	.....
Water H^2O	1 90	.....	0 54	0 70	.....
Total	99 65	97 91	99 81	100 62	98.485

TABLE OF TENSILE STRENGTH OF VARIOUS BRANDS OF NATURAL AND ARTIFICIAL CEMENTS.

ALL SAMPLES ARE UNIFORMLY OF ONE SQUARE INCH SECTION.

Age of specimens, after being allowed 1 hour in air, balance of time in water.

Name of Brand.	1 Dy.	2 Dys.	1 Week.	2 Weeks.	1 Month.	6 Mths.	1 year	2 yrs.	3 yrs.	Authority.	Remarks.
Louisville	72.2	78.7				150.6				Journal Assoc. Eng. Societies, page 187, Vol. V.	
Rosendale	49.0		73.0		156.0	286.0				Journal Assoc. Eng. Societies, page 187, Vol. V.	
Average of 25,000 samples of American cements	71.		92.0		145.0	282.0	290.0			Eliot C. Clark, Boston Main Drainage Works.	
Napanee	50.		90.0		140.0	280.0	300.0	315		M. J. Butler, the two year old samples were from a lower grade of cement, thence do not show as great strength in proportion to age.	
Artificial *.			280. not	broken	at 1 year	8 mos.	275	broke	it.	These two briquettes were composed of common lime and clay burned together and ground finely.	
" *			390. "	"	"	"	290	"			
Portland Cement.	102.		303.		412	468	494			Eliot C. Clark, Boston Main Drainage Works.	
Alsen & Co., Portland	170.		275.	340	467	561	690			E. J. De Smedt, Foreign, Portland.	Rep'rt District Columbia, 1885.
J. B. White	95.		200.	268	364	400				" " " "	
Giant	150.		335.		416	673	700			" " American "	
Egypt	100.		270.		355	"				" " " "	

NOTE—The two samples of artificial cement shew that it is quite possible in short time tests to get a high result from an inferior article, as these samples deteriorate with age.

DISCUSSION.

Mr. Hannaford. Mr. Hannaford said his experience with natural cements was not so favourable as with artificial cements, and that with the former the bulk was often inferior to the samples. In explanation of this, it may, and no doubt does, arise from the fact that the stone from which natural cement is manufactured is in beds, adjacent and mixed with ordinary limestone, and that the assorting of the one from the other, and the selection of the natural cement stone, even within its own compass, requires the most careful attention of experts, and that when a demand is made upon natural cement works for a large supply, it is reasonable to suppose that the selection of the stone is apt to be hurried; but be that as it may, his experience has been that as a rule natural cements do not hold their character throughout bulk, like artificial cement, and hence in carrying out works (especially under contract) this element affords much anxiety.

But assuming that the difficulty above mentioned may be overcome by care in selection and systematic manufacture, this process means additional cost; still, even so, can the output of natural cement meet the market demand, and is it equal to the artificial cements?

He was unable to give a reply to the first query. There are several natural cement works in Canada, and all alike praise their output; but in regard to equality with artificial cements, his experience has been that none of them are to be relied upon in bulk for doing work equal to artificial cement. Artificial cement (Portland) has the qualities of quick setting, great cohesion, and resistance of sea water beyond all others, whilst it can be used freely with water to form "grout," which natural cements cannot be, and whilst water may be used freely with artificial cement, it must be used sparingly with natural cements.

In the way of concrete his experience has been that artificial cement was preferable to natural cement, and that he had failed to obtain results of hard setting in water from natural cement, whilst in sea water it refused to set. He had used natural cement in concrete but invariably laid in air.

Mr. W. E. Gower thought that Mr. Hannaford's claim as to the unreliability of the cement was fully borne out by the figures given by Mr. Butler, who gave 7 days' test at 90 lbs., one month's at 140, and 6 months' at 280. The figure given by Mr. Bravender showed a 7 days' test at 135 lbs. and a 27 days' test at 200 lbs.; but on referring to a paper read before the Society by Mr. Rust, on the Construction of Sewers in Toronto,* he found the results of tests of Napanee cement showed for a 6 days' test 39 lbs. per sq. in. only, and a 30 days' test 76 lbs. only; these figures were considerably less than 50% of those given by either Mr. Bravender or Mr. Butler. He thought there was no doubt that Canadian cement could be made to stand a very high test, although he had not arrived at the figures given by the gentleman who said that he had tested the Hull cement and had attained the result of 676 per sq. inch for 7 days. He understood that the highest test cements known at present were German cements, and for a 7 days' test these did not attain the figures of the Hull test. In February, 1889, he tested four briquettes of artificial cement, and the result was from 325 to 219 lbs., one giving a very low test, the average being 292 lbs. for a 7 days' test. Mr. Gower.

Mr. Reid said it would not be prudent for him to say much about the quality of cement made in different parts of Canada. There could be no doubt that there was an abundance of suitable material here. The first Portland cement he made was in 1869 in Halifax, N. S. Material there was abundant and fuel cheap. A quantity of cement was then being sent out by the British Government for the harbour fortifications, and he made some native cement and subjected it to a test made by the Royal Engineers, then stationed there. At that time—21 years ago—Portland cement was scarcely known in Montreal, and comparatively little of it was used in New-York. He commended Mr. Thos. Arnold's method of testing samples:—Each of his small briquettes contained 135 grammes of cement compressed into a dry mould by screw pressure, which were then treated in water. Mr. Reid.

Mr. Dodwell considered that one of the most important features in the cement discussion was the desirability of a uniform system of testing. The want of such a system has been one of the great defects and difficulties in comparing tests of one cement with that of another, the systems of testing having been dissimilar, and anything Mr. Dodwell.

* "Construction of Toronto Sewers," by C. H. Rust. Transactions, Vol. II, page 302, November, 1888.

that would tend towards uniformity in the testing of cement would be of very great advantage.

Prof. McLeod. Professor McLeod asked if in the method mentioned by Mr. Reid the pressure was uniform ?

Mr. Reid. Mr. Reid said the pressure was uniform, because the plunger was made precisely to fit the briquette, and when pressed down level it left exactly the space of one inch.

Prof. McLeod. Professor McLeod understood the pressure was measured in that way by the volume which the powder occupied.

Mr. Reid. Mr. Reid said that a briquette mould would contain 135 grammes under certain pressure, and that this could not be overdone or over-strained so that there was uniformity in every briquette; a little tray filled with water was used in which the briquettes were placed.

Prof. McLeod. Professor McLeod thought different cements would have different gravities, and it could not be expected that the same weight would always occupy the same volume.

Mr. Dodwell. Mr. Dodwell did not think the Arnold system was quite free from objections in some points, but the great point was that if it could be universally introduced as a standard of cement tests, that would be sufficient, as results would then be comparable, and the objections would be of no moment.

Mr. Hopkins. Mr. Hopkins considered that if there was a good deal of material containing iron ore it was better by not being tested in amounts of 135 grammes as the density would not be as great. That seemed to him to be the chief objection, because of the testing by the same unit of weight instead of volume.

Mr. Reid. Mr. Reid asked if that would not be apparent in the result of the briquette test ?

Mr. Irwin. Mr. Irwin said in any case cement was sold by the barrel, and its value determined by volume instead of by weight. He considered a good testing machine was much required.

Professor McLeod said he had asked the question because he thought that possibly there was some arrangement in Arnold's test, whereby a uniform pressure was obtained independent of volume. If, for example, the pressure were exerted against a spring, it would always be the same, and the briquette subjected to the same pressure. He could easily imagine some little adaptation for measuring pressure which would overcome the difficulty mentioned. Prof. McLeod.

Mr. Dodwell said the result of the method of compressing a briquette into a certain size would favour a light and a finely ground cement. A higher tensile strength would be obtained with a fine rather than with a coarse cement. The more a cement was compressed into a briquette the greater would be the tensile strength resulting. Mr. Dodwell.

Mr. Reid did not agree with this. When cement was in rougher particles it possessed some solidity, and when it was pressed in by the mechanical process mentioned there was a tendency to give it a uniform density. Mr. Reid.

Mr. Blackwell considered the machine would insure the briquette being filled at a certain pressure. Mr. Blackwell

Mr. Gower said it also insured the pressure being distributed all over the briquette, which was not accomplished by the use of the trowel. If it was required to increase the tensile strength per square inch, hammering was resorted to, and the more it was hammered the greater the result obtained. Mr. Gower.

Professor McLeod mentioned another objection to this method of testing. He thought that material should be tested as far as possible under conditions similar to that under which it was going to be used. It did not seem to him that this was a condition similar to that under which the cement would be used; the old method of testing was more in acordance with what the cement would be called upon to do in actual work. Prof. McLeod.

Mr. McLea Walbank did not understand what the method was of testing the special brands of cement for comparison; but in his opinion cement should be tested barrel by barrel as used. Mr. Reid's test would be a fair one, because the same brand would in nearly every Mr. Walbank.

case be used throughout the works, and the consistency or specific gravity would be practically the same. It would be cumbrous to transport a testing machine as large as six feet square.

Mr. Irwin. Mr. Irwin understood Mr. Reid's method was for getting the cement into shape, and not with regard to the form of the testing machine.

Mr. Walbank. Mr. Walbank considered that every barrel should be tested.

Mr. Gower. Mr. Gower observed that to do this with a 7 days' test all the shipment would be used up before obtaining the result. He said that tests of Thorold cement gave 42 lbs. 6 days in water, 85 lbs. in 30 days.

Mr. Dodwell. Mr. Dodwell said the tests recorded in the paper and in the discussion varied very much, from 39 lbs. to 90 and 135 lbs. He considered cement that varied so widely to be unreliable.

Mr. Irwin. Mr. Irwin said his experience with Thorold cement was that it contained an excess of lime.

Mr. Hopkins. Mr. Hopkins stated that he had seen cement used in very cold weather on bridge masonry, the low temperature making no difference so long as the cement did not thaw out.

Mr. Dodwell. Mr. Dodwell observed that he had often used Portland cement for masonry, when the temperature was 10° below zero Fahr., the cement and the joints proving as hard as if laid in summer. If it should thaw before setting then the cement would be impaired.

Mr. Walbank. Mr. Walbank said he had used Portland cement at the Grande Mare Falls on the St. Maurice river at 20° below zero Fahr. There was a very heavy wall over 20 ft. wide at base to dam a 40 ft. head of water, and they built it in a hurry during the winter. Portland cement was used, the sand used with the cement was heated, and a little salt was put into the water used in mixing the cement. Experiments showed that alternate freezing and thawing did not produce any appreciable effect.

Mr. Dodwell. Mr. Dodwell considered there was not enough known about the

action of frost upon cements. He had noticed but few instances of failure of cement owing to frost. He did not refer to "face" work. The question of Canadian cements was one worthy of discussion. If cement *could* be made here it should be manufactured and used. All the material was here, and it only required men who understood manufacturing it. He thought that as a rule natural cements were poor substitutes for artificial cements, as they could not be guaranteed, and their reliability could only be ensured by frequent tests.

Mr. St. George observed with regard to Canadian cements, that it had been mentioned by the author that their strength increased with age, while Portland cement, it was stated, deteriorated. He had prepared a table giving particulars of tests for one year of different brands of cement, (see page 110), which the Quebec Government had embodied, with a report on cements, in the Annual Report of the Minister of Public Works. Mr. St. George.

A German, whose name he had forgotten, had gone thoroughly into this question, and had made one series of tests altogether in water and another series altogether in air, differing from the English practice of testing cement by first allowing it to set for 24 hours and then putting it into water. The speaker had experience with many brands of cement,—English, German and Canadian,—and after a test of 7 days (one in water) with pure cement he found that the German (Dyckerhoff) cement had a tensile strength of 445 lbs. per square inch. Some of the English cement (Johnson's) reached 330 lbs. Of the Canadian cements, the Quebec stood the highest, being 110 lbs., Thorold 80 lbs., Napanee 65 lbs., and Hull 50 lbs., all mixed neat. With one of cement and one of sand the German reached 220 lbs., Johnson's 130 lbs., Quebec 35 lbs., Thorold 30 lbs. The Napanee showed no result. With one of cement to two of sand there was a gradual decline, the German showing 110, Johnson's (English Portland) 60, Quebec 20, Thorold, Napanee and Hull no result.

Referring to the 7 days' test, 24 hours in air and 6 days in water, the speaker remarked that Johnson's (neat) showed 260 lbs., the Quebec no result at all, and the Thorold 40 lbs.; and with equal parts of cement and sand there was no result with Canadian cements. The other results gradually lowered, 180 lbs. for the German down to 90 lbs. for Johnson's Portland with a 30 days' test.

The author of the paper had stated that foreign cements did not improve with age, but the speaker found that the German ran up to 520 as against 460, and taking the English cements,—Johnson's or

Table of Tests of Cements.

	Name of Maker or Brand.	7 Days Test Dry.			7 Days Test Wet.			30 Days Test Dry.			60 Days Test Dry.			100 Days Test Dry.		
		Neat C. Cement Lbs.	1 of C to 1 of S, Lbs.	1 of C to 2 of S, Lbs.	Neat Cement Lbs.	1 of C to 1 of S, Lbs.	1 of C to 2 of S, Lbs.	Neat Cement Lbs.	1 of C to 1 of S, Lbs.	1 of C to 2 of S, Lbs.	Neat Cement Lbs.	1 of C to 1 of S, Lbs.	1 of C to 2 of S, Lbs.	Neat Cement Lbs.	1 of C to 1 of S, Lbs.	1 of C to 2 of S, Lbs.
Foreign.	Dyckerhoff...	445	220	110	373	180	102	588	285	200	850	345	215	885	355	245
	Josson.....	440	210	106	360	175	95	.....	.....	.....	.....	.....	.....	.....	.....	.....
	Farrick.....	363	235	108	.....	.....	.....	.....	.....	.....	433	205	150	535	238	175
	Alsen.....	340	160	110	275	173	125	560	283	180	635	320	210	700	330	215
	Zung.....	320	140	90	.....	.....	.....	445	170	112	460	195	120	585	280	195
	Vicat.....	340	118	80	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	Talbot.....	305	125	65	295	110	45	345	130	80	370	135	90	392	180	125
	Excelsior.....	305	165	90	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	Delbende.....	240	133	90	.....	.....	.....	.....	.....	.....	515	233	118	650	250	155
British.	Johnson	330	110	63	260	95	55	.....	.....	.....	390	160	70	585	268	112
	Robins.....	325	177	100	.....	.....	.....	406	200	108	420	215	115	.....	.....	.....
	Knight, B & S	325	75	35	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	Frances.....	300	115	60	255	90	55	395	173	112	418	245	130	450	270	148
	Burham	300	150	90	300	170	73	.....	.....	.....	.....	.....	.....	.....	.....	.....
	Jarrow.....	195	80	45	.....	.....	.....	200	100	68	285	125	75	375	170	85
	White	280	143	55	260	118	55	395	150	60	475	200	100	538	210	128
	Union	275	120	55	260	65	25	400	163	105	500	180	110	538	245	148
	Bull.....	265	133	105	210	100	63	.....	.....	.....	430	210	155	520	256	175
	Brooks.....	240	90	65	338	165	70	.....	.....	.....	.....	.....	.....	.....	.....	.....
	Hoyle-Robson	240	125	70	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	Gillingham...	335	65	35	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Canadian.	*Point Claire.	345	130	45	325	165	80	.....	.....	.....	.....	.....	.....	.....	.....	.....
	Wright.....	275	No samples		.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	Quebec	110	38	20	No	result	.....	168	110	60	187	120	85	268	125	85
	Thorold.....	85	33	No res	45	No	result	108	50	10	125	75	60	155	100	68
	Napanee.....	55	No result		.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	Hull.....	50	No result		.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

N. B.—The average of three bricquets was taken in all cases, and the results arrived at indicate the tensile strength per square inch.

*Laboratory test.

White's,—they went up in the same manner. The Quebec cement neat increased from 110 to 170, the Thorold being only 82 lbs.

With one of cement to one of sand they had also all increased, the Quebec with only 48 lbs. increased after 30 days to 110 lbs. With the test of 60 days it was found German cement reached 850 lbs. (neat), the Quebec increasing after 30 days 170 lbs. to 185 lbs., a gradual increase ; but when the natural cements were mixed with sand they did not stand at all except after 60 days, the Canadian cements taking a long time to set.

Cements were made for a certain purpose, viz., to enable works to be constructed in as short a time as possible. The Craig street sewer, Montreal, built in 1840, with plain lime, was taken out in 1885, when the mortar and brickwork were a solid mass. He desired to state as his experience that artificial cements improved and did not deteriorate by age, as Mr. Butler's paper describes.

Mr. J. Kennedy observed that the paper mentioned the time as after three or four years. Mr. Kennedy.

Mr. St. George thought that if 60 days' test showed that the artificial cements increase in the ratio stated, it was not probable that they were going to fail. This was not the case in any works he had seen, nor did he think Mr. Kennedy had ever had such experience with Portland cements. White's cement (Portland) pure showed, with a test of 7 days in air, a tensile strength of 280 lbs. Mr. St. George.

The figures tabulated were the highest that could be obtained here, and the Quebec test of some hundred samples gave results very near the figures.

Mr. K. W. Blackwell said that some of the table books gave results as high as 1200 lbs. Mr. Blackwell.

Mr. Kennedy asked Mr. St. George how it was known that the mortar in the old Craig street sewer was common lime, because at that time Canadian cement was generally well known. His recollection made it difficult to tell whether the mortar was made from natural Canadian cement or common lime. Mr. Kennedy.

Mr. St. George replied that when the Craig street sewer was broken down, the mortar was quite white and colorless. In those days in Montreal lime was slacked a long time in advance of being used, as is Mr. St. George.

now done in Germany, where lime is slacked in large vats and sold according to its age.

With regard to high tensile strength of cements, he found that in Belgium, in order to obtain these results, the water was extracted from them. In that way a higher tensile strength could be obtained, but tests should be made under circumstances similar to those under which it was to be used. In his opinion the best way to make a test so as to obtain the actual quality of the cement was not only to take the pure cement, but to mix it with sand, one to one and two to two. It had been seen that some cements could not stand sand at all, and that although good when pure, they would not work with sand. The crushing of the cement was another important factor. At some factories he had seen cement come from the kilns quite black. Such had not been properly burnt, and should be raked on one side, recrushed and reburnt. Last year he had experience with a good brand of imported artificial cement. It did not set well, and whilst in that state spewed up a black oily substance with a scum on the top, and under the scum ($\frac{3}{16}$ of an inch thick) it was quite soft and had not set at all; this was owing to not being properly burnt. Robin's cement was good, but the charges were from 5 to 8 per cent. higher than for any other make.

Mr. Ruttan. Mr. Ruttan said he was glad to see from the paper that there was a prospect of their having a good Canadian cement, that makers of these cements had pressed their use with engineers, and the latter had been censured by the makers for not using them. But the fact was, experience had proved that Canadian cement was not satisfactory. The chemical constituents of the cement were said to be all that is required, and if this were so he was led to believe that the fault must be in the manufacture. He thought the sooner Canadian manufacturers were brought to realize the fact that their cement was not what is required, the sooner they would endeavour to improve. The quality of cement was not a matter of opinion, but the result of tests. Engineers would be glad to use the native cements if they came up to requirements. Canadian cements are cheaper than the imported cements, and he thought that there would be no greater demand for the former until the quality equalled that of the latter.

Mr. St. George. Mr. St. George stated that there was a cement he had omitted to mention, manufactured at Point Claire. He had not yet tested it, but he had given Mr. Reid's (the manager) laboratory test in the table.

Mr. Ruttan said it might interest the members to know that within the last year a natural cement manufactory had been established in Manitoba. No practical test had yet been made, but the laboratory tests were said to be very good. Mr. Ruttan

Mr. F. E. Came asked if the tests of the Hull cement were made recently or some time ago? Mr. Came.

Mr. St. George replied they were made in 1889. Mr. St. George.

Mr. Came said the Hull manufacturers claimed to have made recent improvements in their cement. Mr. Came.

Mr. St. George said he was of opinion it could be improved by proper mixing, burning and crushing, and also by keeping it dry when made. Mr. St. George.

From a diagram, showing results of Cement Tests, exhibited by Mr. St. George, Plate VI has been prepared.

CORRESPONDENCE.

Mr. Macdougall

Mr. Alan Macdougall said that the paper dealt with a valuable native industry. It was to be regretted that in the early efforts to manufacture this cement more care had not been taken in selecting the rock. Mr. Butler brings this out in his paper; the result has been that the industry has suffered. The cement is well ground, as the samples produced by Mr. Rust show, and with age the test results are good. It is a slow setting cement. The speaker believed there was a market for it in the province. He hoped the present management would exercise prudence, and not try to place it on the market till they had satisfied themselves as to the quality of the rock, and had brought the manufacture of the cement to a sufficient stage of perfection to produce a reliable article.

Mr. Gauvreau.

Mr. L. P. Gauvreau of Quebec said that the only natural cement of Quebec is manufactured from the black stone adjacent to the city. The method of burning and grinding this cement is similar to that used for other natural cements. The analysis of the stone made by Mr. Delesse, one of the jurors of the Paris International Exhibition, 1855, was:—

Water and carbonic acid.....	52.49
Magnesia	traces
Silica.....	27.40
Alumina and oxide of iron.....	12.16
Sulphate of lime.....	7.95
	100.00

He stated that Quebec cement has been largely used for public and other works in Canada, and with satisfactory results.

Mr. Evans.

Mr. E. A. Evans said Mr. Butler's paper suggests the question: Are the natural equal in quality to the best Portland or artificial cements? In the speaker's opinion, all quick setting and other natural cements are considerably inferior to the slow setting Portland and other artificial cements. Are they then so inferior as to be entirely condemned for use on all public works? He believed not (at any rate for works above

ground), provided that the bulk supplied is equal to the approved sample. Here is the difficulty in the way of the general use of the Canadian cements, viz., their varying quality—utterly bad, inferior and fairly good cement, all being supplied by the same manufacturer as first class hydraulic cement. Mr. Butler admits that it is not at all a simple matter to quickly and satisfactorily test the quality of cement, and until some better and more practical method of testing than at present available is devised, Canadian cements cannot be recommended for any foundation or hydraulic works. He did not admit that the cements showing a high tensile strength grow inferior with age, crack and peel off, as stated by Mr. Butler, but that in his experience such failures refer only, in certain instances, to surface work generally imperfectly done.

Mr. H. H. Killaly said that previous to last August, Napanee cement had not been used upon any of the works under his charge; that recently a small quantity of this cement was used at Lock 21 on the Cornwall Canal enlargement; that for concrete it was very slow in setting, and for this reason its use was discontinued; that subsequently Napanee cement was used in building some of the masonry of the same Lock; but that he was not then able to say how this cement had behaved when used for concrete. Mr. Killaly.

Mr. C. H. Rust said that during the last seven years he had frequent opportunities of testing Canadian cement in the construction of sewers in Toronto. The tests were all made with a Riéhlé testing machine. The results so far with Canadian cement have not been satisfactory, and owing to the unreliability of these cements, the use of both Thorold and Napanee have been nearly discontinued in favor of Portland. The great fault of the Canadian cements is their tendency to "blow." This was not so pronounced in the Napanee as in the Thorold, but in tensile strength both are deficient. He considered this deficiency largely due to the fact of the manufacturer not using sufficient care in selecting the stone. He is glad to see that Mr. Butler calls attention to this important feature. He stated that the City Engineering Department of Toronto used 12,000 to 15,000 barrels of cement annually on its sewers alone. It will be seen by the table of tests on pp. 116-117 that no such result as that mentioned by Mr. Butler has been reached with Napanee cement, the highest tensile strength, after being 6 days in water, being 40 lbs. per square inch. He considered the method of making tests of sample briquettes open to objections, his experience Mr. Rust.

being a much lower result than claimed by some cement agents. According to his experience in the use of natural Canadian cements the mortar should not be weaker than 1 to 2.

TESTS OF NAPANEE CEMENT MADE IN CITY ENGINEER'S OFFICE, TORONTO, 1886 TO 1889.

TIME IN WATER.	TENSILE STRENGTH PER SQ. INCH.	PROPORTIONS.
1 Year	180	Neat
1 "	200	"
30 Days	76	"
6 "	40	"
1 Year	150	"
30 Days	25	"
	1888-9	
6 Days	12	
6 "	18	
15 "	22	
28 "	53	
500 "	275	
150 "	130	
6 "	25	
18 "	40	
6 "	20	
6 "	10	
6 "	10	
35 "	12	
26 "	50	
100 "	80	
8 "	6	
5 "	6	
150 "	113	
135 "	135	

The two last tests are from a batch, the rest of which went to pieces when first placed in water.

MARCH, 1890.

AGE OF BRIQUETTE.	TENSILE STRENGTH PER SQ. INCH.	REMARKS.
190 Days	174 lbs.	Sent from Napanee by E. Bravender.
289 "	636 "	do
24 "	120 "	do
400 "	222 "	do
2 Yrs. 90 Dys.	109 "	do
2 " 227 "	151 "	do
3 "	123 "	do
2 " 212 Dys.	151 "	do
2 " 242 "	150 "	do
2 " 242 "	101 "	do
2 " 273 "	140 "	do
170 Days	421 "	Sent from Napanee by Mr. Terry
1 Year	275 "	" " do
1 "	297 "	Moulded by do
1 "	204 "	" " do

THOROLD CEMENT.

TIME KEPT IN WATER	AVERAGE STRENGTH	
6 Days	30 lbs.	
30 "	75 "	
100 "	200 "	
	Buffalo, U. S.	
6 Days	50 lbs.	
30 "	75 "	
100 "	200 "	
	Syracuse, U. S.	
6 Days	200 lbs.	American Portland
30 "	400 "	" "
100 "	446 "	" "

Mr. Gray said that Mr. Butler, after stating that the cause of the failure of the Napanee cement is owing to the mode of manufacture, says that under his instruction and advice tests were made of the several layers of the quarry by graduating the intensity of the heat in the roasting or burning. It appears to him that this is just the reverse of what is necessary to obtain the qualities for a good cement. He considered that the proper method to insure a good cement being manufactured is to have the raw material of stone chemically analyzed *before* being roasted and ground. It is found indispensable to do this with the raw materials of iron and steel. The value of the manufacture depends more on the obtaining and selecting of the raw material which contains the least amount of deleterious elements, than in the elimination of such elements. It is easy to understand how iron and other manufactures would suffer if their make depended upon the very scant knowledge applied to the manufacture of cements. The result is that the contractor or engineer receives as cement a substance of undetermined composition, varying in quality with every circumstance of its manufacture and every condition of its storage and preservation, and from this by the addition of sand water, etc., he must compose a material, the strength of which he is to determine, although every method in combining the ingredients will affect the results.

Mr. Gray.

Mr. M. J. Butler stated in reply that it was not his intention in the paper to convey the impression that good Portland was inferior to natural cements. An instance was given when two samples of an artificial cement prepared from common lime and clay, without regard

Mr. Butler.

being had to any particular proportion, gave on short time test a high tensile strength which they afterwards lost. The object being to record a mild protest against the present tendency of calling for a very high tensile strength on a seven days test.

Over-clayed cements set quickly; hence, if specifications, require a high tensile strength in short periods of time, manufacturers will endeavor to comply with this demand by every means available, among which are over-claying, the addition of sugar or molasses, and extremely fine grinding (this latter being doubtless a permanent benefit). The ultimate effect of over-claying cements is to weaken them. Eliot C. Clark, M. Am. Soc. C. E., in his paper read before the American Society of Civil Engineers, describes a new brand of cement which was made by some patent process, which at the end of 7 days tested neat 184 pounds, in a month it reached 267 pounds, but in six months the briquette fell to pieces. He also makes the instructive remark that absolute uniformity in breaking need not be looked for, as he expressed it, "the sample declined to break by formulæ."

Mr. Hannaford points out very clearly the causes that have led to lack of uniformity in natural cements. That cements containing magnesia are best for sea water constructions is generally admitted. It does not seem necessary to quote from the various recognized authorities on the point. The proof contains an analysis of Quebec cement, it is thought worth while to point out the fact that as given the elements to make a cement are not present, and doubtless there is an error in the reading.

Since the paper was prepared the writer has paid particular attention to the examination of the exposed parts of old works laid up in Portland cement. The pointing being usually the only part visible, he has not yet seen one place where it has not been cracked and where it could not be picked out by a little effort. The cement is very hard and brittle, and would under tensile test doubtless show a high resistance to breaking. Under water the cracks do not appear.

With regard to the remarks of Mr. Killaly, the writer is informed that Napanee cement was delivered to the works at Cornwall under his charge about two years ago, that all of the concrete has been made with Napanee cement, that the bulk of the masonry, including the pointing, has been done with Napanee cement, and that the work is in first class condition.

Mr. Rust's table of test samples is interesting, the date given by the writer is based on about 200 samples, and that given by Mr. Bravender is based on upwards of 1,000 samples.

The manner of preparing the briquette, the temperature of the air and water, the quantity of water used, and the method of treating the briquette after and before filling, are all factors in determining the final result, and but emphasize the fact that a uniform method is most desirable. The writer begs to suggest that a committee of the Society be appointed for the purpose of recommending a uniform system of testing and to prepare a specification for quality. The fact is that natural cements should never have more than two parts sand to one cement, and in important work one and one-half sand to one cement.

Mr. St. George is mistaken in assuming that the writer claimed that Portland cements deteriorate with age, so far as the *tensile testing machine would show.* Under water there is no doubt that they are practically everlasting (so far as our knowledge goes), but in air or sea water there is, to say the least, some doubt of their lasting properties. Common lime will never stand in water, even if mixed for centuries, when placed in water it will go to pieces; hence, if the sewer in question has stood, the lime must have been an hydraulic lime. The quotation from Mr. Clark and the writer's own tests show that even after sixty days a cement may fail, and fail badly.

Mr. Gray thinks the writer erred in directing the cement manufacturers as he did; if so, he was in good company. It is precisely the method followed in all of the natural cement works in the world. It is the method advised by Gilmore in his "Limes, Cements and Mortars."

As the paper shows, frequent chemical analyses were made both of the rock and of the cement, for the chemists are by no means agreed on what constitutes a first class cement, and it is only by practical test on a large scale that a reliable result can be hoped for. The chemical analysis is a useful guide to show us that we are not trying to work against natural laws, but no laboratory work can supersede the actual test on a large scale.

Thursday, 27th February,

C. E. W. DODWELL, Member of Council, in the Chair.

The following candidates having been balloted for were declared duly elected as :—

MEMBERS.

MOSES BURPEE,
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JAMES MOORE SHANLY.

The following were transferred from the class of Students to that of Associate Members :—

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CHARLES DANIEL SARGENT.

The following was transferred from the class of Associate Members to that of Associates :—

GEORGE R. HOOPER.

The discussion of Mr. M. J. BUTLER'S paper on "The Manufacture of Natural Cement" occupied the evening.

Thursday, 13th March.

E. P. HANNAFORD, Vice-President, in the Chair.

Paper No. 40.

COLUMNS.*

By Charles F. Findlay, M. Inst. C. E.

In the whole range of subjects with which the art of engineering is concerned, there are few in which theory has contributed less to the advance of intelligent practice than in this. The reason cannot be found in any want of importance in the subject itself, for, of the materials used in construction, a much greater part is used in compression than in tension, and a very considerable part is used in the form of columns or struts. Until recently the experiments on compressive strength were very few in number and narrow in range, compared with the multitude of tensile experiments that have been made. Even now, many of the laboratories with expensive and elaborate apparatus for tensile tests have no means of making compressive tests. Of late years, however, American experimenters have done a great deal to remedy this state of things, among whom Mr. Christie, Mr. Bouscaren, and Messrs. Clarke, Reeves & Co. may be mentioned in particular.

What is now wanted even more than experiments, is a theory of the subject which will enable us to interpret their results in a general way, and also to indicate the kind of experiments desirable. We shall therefore attempt here to give a treatment of the subject somewhat more rigourous than is usually found in text books.

A column differs from a beam or girder in the nature of the forces it is intended to resist, a beam being used to resist forces transverse to its length, a column to resist forces directed between its two ends. Of course, the same material may be used to resist forces of both kinds at once, but for the sake of clearness we shall neglect transverse forces altogether in treating of the column. The leading feature in the behaviour of a loaded column is that it bends, the deflection constantly

* This investigation coincides in certain parts with papers by Professors Ayrton and Perry, in the *Engineer* (London), December 10th and 24th, 1886, and by Professor Krohn in the Proc. Am. Soc. C.E., 1887.

increasing with the load. The stress which might at first be almost uniformly distributed in the column, becomes thus more and more unequal at the outer and inner edges as the load increases. With a tensile stress on the other hand, although a small flexure undoubtedly must result from the same causes that give rise to flexure of columns, the direction of the flexure is opposite, and therefore tends to produce a more uniform distribution of stress. The difference between the two cases may be illustrated by that between stable and unstable equilibrium.

The equation which forms the basis of all investigations into the flexure of beams and columns is

$$(1) \qquad M = EI\left(\frac{1}{R} - \frac{1}{R_o}\right)^*$$

where M = moment of external forces at a cross section of the beam or column, whose moment of inertia about an axis through its centre of gravity at right angles to the plane of flexure is I;

R = radius of curvature of axis of beam or column at same cross section, and R_o = initial value of R when M = 0;

E = modulus of elasticity of material.

By the axis of a column we here and hereafter mean the axis of figure and not the neutral axis (which for columns generally lies at a considerable distance outside the column).

It will be well here to call attention to the assumptions on which (1) rests, because it has often been applied to circumstances in which it is not true, and most misleading conclusions have been drawn in consequence. Equation (1) supposes:

First, that every plane section of the beam or column normal to the axis in the unstrained state remains plane and normal to the axis throughout. This is probably approximately true for homogeneous beams or columns formed out of one mass of uniform material, as, for instance, a log of timber, a cast iron column, or a rolled joist, but it is very doubtful how far it can be relied on for a framework built up of a number of separate pieces.

Secondly, that the value of E is constant throughout the cross section. This is approximately true in most cases, and it can be shown

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* This equation is usually given as $M = \frac{EI}{R}$, thus assuming the initial form of the axis to be a straight line. For a beam, although the assumption cannot be true in fact, it does not affect the distribution of stress in the beam. With a column, however, the correction is of vital importance, as we shall see.

that the variations of E occurring in practice cannot largely affect the strength of iron columns, though some writers have attached an exaggerated importance to this point.

Thirdly, that the fibres of the beam or column are all strained in accordance with Hooke's Law. As soon as the most strained fibres pass the limit of elasticity, equation (1) ceases to express the condition of equilibrium, and all conclusions based on it cease to have any application. When therefore, as is sometimes done, a comparison is made between the stress in the extreme fibres of a beam as deduced from equation (1), when M is the moment causing fracture, and the direct tensile stress the same fibres will bear in a testing machine, it should cause no surprise that there is an enormous discrepancy. Equation (1) is based upon a supposed distribution of stress throughout the various parts of the cross section which is utterly wide of the truth when the moment of flexure is such as to cause rupture.*

Equation (1) being the equation of moments at any section of a column, we have also an equation between the sum of the applied forces parallel to the axis and the sum of the internal stresses at the same cross section which will be found to be:

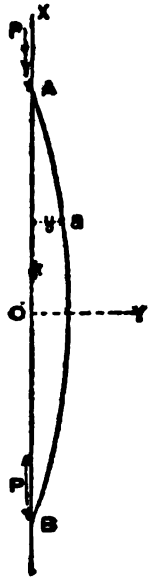
$$(2) \qquad p = \mathrm{E}y_1 \left(\frac{1}{\mathrm{R}} - \frac{1}{\mathrm{R}_0}\right) \text{ whence by (1) } y_1 = p\,\frac{\mathrm{I}}{\mathrm{M}}$$

where p is the total applied force per unit of area of cross section, and y_1 is the distance of the neutral axis from the axis of figure at the same section.

In order to determine M we must know the form of the bent column under a given load, and in order to ascertain that, equation (1) must be solved. Now the essential difference between a beam and a column as regards this solution is, that for a beam M is independent of the deflection, while for a column it depends directly on the deflection. In other words, if x and y be rectangular co-ordinates defining the position of any point on the axis of the column, x being measured parallel to the length of the column, M is for beams a function of x only, while for columns it is a function of y. This entirely alters the character of the differential equation to be solved, and makes it quite inadmissible to assume, as is frequently done, that the deflections of a column will be governed by the same laws as are deduced from equation (1) for beams.

* For a full discussion of the question of the relation of transverse to direct strength of iron, v. Etudes sur l'Emploi du fer et de l'acier, by M. Considère, Paris, 1886.

Let AQB be the axis of a column bending under the action of a load P. Take AB as axis of x, its middle point O as origin, and let $AB = l$. Since the equilibrium of the column as a whole requires



that the forces acting on its two ends should be reducible to two equal and opposite forces P, let the line of action of these forces be at a distance a from O and we shall suppose it parallel to AB, because it is found that the principal effect in producing flexure is due to the mean value of the eccentricities of the loads at the two ends. Of course a is small since the intention is supposed to be to load the column so far as possible centrally. Let a be the cross section of the column at Q, and let $pa = P$. Let y_0 be the initial value of y for the unstrained column. We shall suppose $x_0 = x$, thereby neglecting the elastic shortening of the column. Let ρ = radius of gyration at Q, $= \sqrt{\frac{I}{a}}$; then since $\frac{1}{R} = \frac{d^2y}{dx^2}$ as long as R is very large; similarly $\frac{1}{R_0} = \frac{d^2y_0}{dx^2}$; and since $M = -pa\,(y+a)$, (1) becomes

$$-p\,(y+a) = E\rho^2\left(\frac{d^2y}{dx^2} - \frac{d^2y_0}{dx^2}\right)$$

write for brevity k^2 for $\frac{p}{E\rho^2}$ and suppose k to be constant throughout

the length of the column, *i.e.*, suppose the column to be uniform in section and in material.

Then $\frac{d^2y}{dx^2} - \frac{d^2y_0}{dx^2} = -k^2(y+a)$

To solve this equation we must know what $\frac{d^2y_0}{dx^2}$ is in terms of x, or, in other words, what the unstrained form of the axis is. It being supposed that the column is initially as straight as the ordinary conditions of manufacture permit, the actual form of the axis will be an irregular curve departing very little from the line AB. We shall assume that the curve is the curve of sines $y_0 = \delta_0 \cos \frac{\pi x}{l}$. This assumption can be justified by the fact that the curve, whatever its form, can be expressed by equating y_0 to an infinite series proceeding by sines and cosines of multiples of $\frac{\pi x}{l}$ of which $\delta_0 \cos \frac{\pi x}{l}$ may be considered the first term. If this be done, it will be found that in ordinary cases the effect of the successive terms of the series on the resulting solution rapidly decreases.

We have then $\frac{d^2y_0}{dx^2} = -\delta_0 \frac{\pi^2}{l^2} \cos \frac{\pi x}{l}$

and $\frac{d^2y}{dx^2} = -k^2(y+a) - \delta_0 \frac{\pi^2}{l^2} \cos \frac{\pi x}{l}$

The solution of this equation with the conditions that $y=0$ when $x = \frac{l}{2}$ or $-\frac{l}{2}$ is:

$$(3) \quad y + a = a \frac{\cos kx}{\cos \frac{kl}{2}} + \frac{\delta_0}{1 - \frac{k^2 l^2}{\pi^2}} \cos \frac{\pi x}{l}$$

Before proceeding to obtain from this equation the stresses in the column, it will be well briefly to point out the relation it bears to the theory of flexure given in most text books, and known by the name of Euler's theory from the name of its author, who published it in the middle of last century. In that theory δ_0 and a are neglected, so that the differential equation is $\frac{d^2y}{dx^2} = -k^2y$. The direct solution of this is $y = A \cos kx + B \sin kx$, and the terminal conditions require $kl = \pi$ and $B = 0$, while A is indeterminate. In other words $p = \pi^2 E \left(\frac{\rho}{l}\right)^2$, and p having that value y may be anything. The same result may be deduced from (3), for if a and δ_0 vanish, y must always be

zero except when $kl = \pi$, and in that case $\frac{a}{\cos \frac{kl}{2}}$ is an indeterminate fraction for which an arbitrary constant A may be substituted.

This theory is not only inconsistent with facts, which might be expected from the assumption of ideal conditions that cannot be realized in practice, but in the form given above (which is that usually published) it evidently contains some other serious error; for while it is quite conceivable that under the ideal conditions supposed, no flexure can occur until p reaches a certain limit, it is not conceivable that the flexure, when it does occur, should be independent of the load, so that the same load which first causes flexure will bend the column double. The error lies in neglecting the elastic shortening of the column. In the theory here given this is permissible, but in Euler's theory, a and δ_0 being neglected, a different order of small quantities is dealt with and the contraction of the column becomes important. If this be taken into account, and p is the load for which flexure first becomes possible, or $\pi^2 E \left(\frac{\rho}{l}\right)^2$ then the deflection δ_1 for a given load p per sq. in. greater than p_1, is given by

$$\delta^2 = \frac{4E}{p} \rho^2 \left\{ \sqrt{\frac{p}{p_1}} - 1 \right\}$$

It must also be observed that although by Euler's theory flexure cannot take place until p reaches the value p_1, it does not follow that it will then occur. For every value of p greater than p_1, there will be two positions of equilibrium for the column, one straight and one curved. The former will be unstable, and the chord of the arc of the bent column will be shorter than the straight column under the same load by an amount $\frac{\pi^2 \delta^2}{4l}$.

The difference in results between Euler's theory and equation (3) is strikingly shown by observing that if either a or δ_0 has any finite value, however small, equation (3) shows that y is infinite for the value $kl = \pi$, where Euler's theory first allows flexure to become possible. It should also be observed that for ordinary proportions of columns p_1 approaches the limit of elasticity of the column, so that at ordinary working loads no flexure would ever occur if Euler's theory applied. For instance, with wrought iron having an elastic limit of 12 tons, the length of a column would have to be more than 100 times its radius of gyration in order that any flexure should occur with a load of 12 tons per sq. in., and 400 times to bend with a load of 6 tons per sq. in. We

have given so much space to Euler's theory only because it has been so widely spread in treatises on engineering subjects and for its historical interest.

We will now return to equation (3), and, before going further, it becomes necessary to distinguish between the various ways in which the ends of the column may be constrained since the value of a depends upon the nature of the constraint.

i. The ends may rest in hinges in which the friction is insufficient to prevent rotation. In this a is independent of p.

ii. The ends may be rigidly attached to fixed objects, in which case a is a determinate function of p. (Flat-ended columns are another variety corresponding mechanically neither with i nor ii, and presenting great elements of uncertainty. As it does not represent any column used in practice we shall not consider it here. The same remarks apply to round-ended columns.)

iii. The ends may be rigidly attached to objects which themselves change in position as the load varies. This is a very common case and is that of the struts of a rivetted bridge, but we shall not deal with it, as it would require a very lengthy investigation. We only call attention to the fact that the conditions vary from those of case ii, and that a rivetted bridge strut has in consequence less strength than a similar strut whose ends are really fixed. Not only does it endure secondary stresses arising from the bending moments applied to its ends by the booms of the bridge, but its axis is thereby thrown out of line, by which its strength is impaired for bearing the direct load. We can refer students who wish to pursue the subject (which is one of great complexity) to Dr. Winkler's treatise, "Theorie der brücken," Vienna, 1886.

Considering case i, we must first remark that a hinged strut differs in no way from a fixed-end strut so long as the friction of the hinges is below its limiting value, or if the circumstances are such that the flexure takes place in some other plane than that normal to the axes of the hinges. Presuming that rotation of the hinges actually occurs, let h be the radius of the hinge, a_0 the distance of the centre of the hinge from the axis of the column, ϕ the angle of friction;
then $a = a_0 \pm h \sin \phi$, where the sign of $h \sin \phi$ depends on the values of a_0 and δ_0, the direction of friction being always opposite to the tendency to rotation at the end. For iron on iron without lubrication $\sin \phi =$ about $\frac{1}{10}$, and $h \sin \phi$ will usually be much greater than a_0.

In equation (3) it is permissible to expand in powers of kl and neglect the higher powers because $kl = \frac{l}{\rho}\sqrt{\frac{p}{E}}$ and must always be

small for such values of p as would constitute a safe working load. This may be verified by calculating the values of y direct from equation (3) for certain cases, and comparing them with the values given by the approximation. If this expansion be made, we obtain

$$(4)\quad y+a = a\left(1+\frac{k^2 l^2}{8}\right)\cos kx + \delta_0\left(1+\frac{k^2 l^2}{\pi^2}\right)\cos\frac{\pi x}{l}$$

$$\text{when } x=0,\ y=\delta_0+k^2 l^2\left(\frac{a}{8}+\frac{\delta_0}{\pi^2}\right)$$

so that the central deflection is $\frac{p}{E}\left(\frac{l}{\rho}\right)^2\left(\frac{a}{8}+\frac{\delta_0}{\pi^2}\right)$

Let r be the distance of the innermost or most strained fibres of the column from the axis and f the stress per sq. in. in them, then, so long as Hooke's Law holds, the moment of resistance of the column may be expressed by $\frac{a\rho^2}{r}(f-p)$ which must therefore be equal to $ap\,(y+a)$.

Therefore $\frac{\rho^2}{r}(f-p)=p\,(y+a)$.

f is greatest where y is greatest, *i.e.* at the middle of the column. Substitute from (4) for $y+a$ and write b for $\frac{a+\delta_0}{r}$ and c for $\frac{1}{r}\left(\frac{a}{8}+\frac{\delta_0}{\pi^2}\right)$. We have then $\frac{\rho^2}{r}(f-p)=p\left\{br+cr\frac{p}{E}\left(\frac{l}{\rho}\right)^2\right\}$

The reason for introducing r into the values of b and c is that a and δ_0 are likely to vary roughly with the size of the column. We have seen that the principal part of a generally will arise from friction and be proportional to the radius of the hinge, and δ_0 is likely to increase with the length of the column with respect to which the diameter is generally fixed. At any rate $\frac{\delta_0}{r}$ will more nearly be independent of the dimensions of any particular column than δ_0 simply.

Rearranging the terms, $f=p\left\{1+\left(\frac{r}{\rho}\right)^2\left(b+\frac{cp}{E}\left(\frac{l}{\rho}\right)^2\right)\right\}$

This is a quadratic to obtain p in terms of f, but b and c being small, we may, as a first approximation, write f for p in the last term inside the bracket, the error so committed being in the direction of safety, and we thus obtain

$$(5)\quad p=\frac{f}{1+\left(\frac{r}{\rho}\right)^2\left\{b+\frac{cf}{E}\left(\frac{l}{\rho}\right)^2\right\}}$$

Case ii. Fixed ends.—Here the terminal conditions are that $\frac{dy}{dx}$ when

$x = \frac{l}{2}$ or $-\frac{l}{2}$, must be constant, whatever the value of p may be. If the same assumption as before with regard to the initial form of the axis be made, these conditions give

$$a = -\delta_0 \frac{\frac{kl}{\pi}}{1-\frac{k^2l^2}{\pi^2}} \cot \frac{kl}{2}$$

or expanding in powers of kl as before $a = -\frac{2\delta_0}{\pi} - \delta_0 k^2 l^2 \frac{12-\pi^2}{6\pi^3}$

The maximum bending moment is in this case at the end of the column and equal to $p\,a$. Proceeding as before to equate $p\,a$ to $\frac{\rho^2}{r}(f-p)$ we obtain a result of exactly the same form as (5), but in this case $b = \frac{2}{\pi}\frac{\delta_0}{r}$ or nearly $\frac{2}{3}\frac{\delta_0}{r}$ and $c = \frac{12-\pi^2}{6\pi^3}\frac{\delta_0}{r}$ = nearly $\frac{1}{87}\frac{\delta^0}{r}$.

The central deflection will be found to be $\frac{12-\pi}{12\pi^2}\delta_0 k^2 l^2$ or nearly

$$\frac{3}{40}\delta_0 \frac{p}{E}\left(\frac{l}{\rho}\right)^2$$

It might, however, perhaps be a fairer assumption for a fixed-end column to suppose the initial form of the axis to be the reversed curve $y_0 = \frac{\delta_0}{2}\left(1+\cos\frac{2\pi x}{l}\right)$, having the same central ordinate δ_0 but tangent to the line AB at both ends. On this assumption a will be found to be equal to $\frac{\delta^0}{2}\left(1+\frac{k^2 l^2}{4\pi^2}\right)$

and the equation to the curve of the axis will be

$$y = \frac{\delta_0}{2}\left(1+\frac{k^2 l^2}{4\pi^2}\right)\left(1+\cos\frac{2\pi x}{l}\right)$$

giving a central deflection due to the load of $\delta_0 \frac{k}{4\pi^2} l^2$ or nearly $\frac{\delta_0}{40}\frac{p}{E}\left(\frac{l}{\rho}\right)^2$. The relation between f and p is of the form of (5) as before, only that now $b = \frac{1}{2}\frac{\delta_0}{r}$ and $c = \frac{1}{8\pi^2}\frac{\delta_0}{r}$ = nearly $\frac{1}{80}\frac{\delta^0}{r}$

The following conclusions may be drawn from the investigation which has resulted in this formula.

First, the actual strength of any column depends partly on known facts with regard to its dimensions, material, etc., and partly on acci-

dental circumstances which can neither be predicted nor observed. This is true in some measure of all constructions, but with columns these accidental circumstances do not merely require corrections in the calculations of strength that would otherwise be true, but are governing factors in the calculations themselves. It follows then that any formula such as (5), supposing the constants determined, should express, not the strength which may be expected from a particular column of certain dimensions and material, but the *minimum* strength which experiments show may fairly be expected with ordinary care and skill in manufacture. The strength of a number of columns apparently alike and loaded alike may be expected to vary widely without apparent cause, and a formula for practical use should express the minimum and not the average of the results given by a very wide and numerous range of experiments.

Secondly, experiments on the crippling or destruction of columns cannot be expected to give coherent results when applied to the determination of the constants in any formula such as (5). The reasons for this have been fully indicated already. The constants can only properly be determined by experiments within the limits for which the column is perfectly elastic, and unfortunately very few experiments have been made of that kind. One method of determining the constants would be to measure the variations of deflection for given increments of load. If δ be the increase of deflection for an increase of load p, we have for a hinged column $\delta = cr \frac{p}{E} \left(\frac{l}{\rho}\right)^2$ and $b =$ nearly $9c$.

For a fixed-end column (on the second hypothesis, which is probably the truer) $\delta = 2cr \frac{p}{E} \left(\frac{l}{\rho}\right)^2$ and $b = 40c$.

Another method of determining b and c is to observe the limit of elasticity of the column as a whole and assume that this corresponds with the stress in the extreme fibres, f being the limit of elasticity of the material under direct stress. In Mr. Christie's experiments (Proc. Am. Soc. C. E., 1884) there are some observations which enable the first method to be applied. In Mr. Bouscaren's experiments (Proc. Am. Soc. C. E., 1880) are some which enable the second method to be applied. Unfortunately the majority of experiments are made on flat-ended columns, and no deduction can be made for our present purpose from them.

According to the experiments mentioned above, it would seem safe

to place c for hinged columns at .05, and b at .45. If then we take E to be 13,500 tons and f (limit of elasticity in direct stress) 15 tons, which figures would apply to mild steel, and if, further, we allow the working load to be half the elastic load, we shall have as the working in lbs. per sq. in. of a mild steel hinged column

$$(6)\quad p = \frac{16{,}800}{1 + \left(\frac{r}{\rho}\right)^2 \left\{ .45 + \frac{1}{16{,}000}\left(\frac{l}{\rho}\right)^2 \right\}}$$

For fixed-end columns it would seem that c might be put at .0075 and b at .3, and the safe load on a fixed-end column in lbs. per sq. in. would then be

$$(7)\quad p = \frac{16{,}800}{1 + \left(\frac{r}{\rho}\right)^2 \left\{ .3 + \frac{1}{120{,}000}\left(\frac{l}{\rho}\right)^2 \right\}}$$

These determinations cannot, however, be recommended with any confidence on such a narrow basis of experiment. They would give higher working loads for long columns relatively to short ones than the formulæ and tables now in use. The fact that they disagree with present practice we do not regard as a condemnation, because present practice judges of the strength of a column for ordinary working loads solely by its ultimate strength, which we regard as a false principle, but at the same time so radical a departure as is now advocated could not prudently be made until a sufficient experimental basis is found for it as well as full theoretical justification.

The method chiefly used by engineers now is to make the working load a definite fraction of the load of rupture as determined by experiments for a similar section, and this is the best plan available; but it must not be supposed that it secures anything like a definite limit of working stress in the column. The term "crippling load" means different things with different experimenters. "Crippling" occurs in various ways with different columns, and the ratio of the crippling load to the elastic load varies very greatly with different proportions of columns. Further, the stress in the innermost fibres of a column at its point of failure is not the ultimate stress of the fibres, or any constant amount whatever.

Thirdly, since f (or more strictly p) is a coefficient of $\left(\frac{l}{\rho}\right)^2$ in the denominator of (5), the question is raised as to whether f should be made the elastic limit of the material in direct compression, and the working load made a definite fraction of the value of p so derived from (5), or whether f should be made the permissible working stress in the

extreme fibres, and the working load p derived directly by (5) from it. The two methods would give different working loads which would agree for short columns and diverge more and more as $\left(\frac{l}{\rho}\right)$ increased, the first method giving the higher load. The first seems, however, the more logical plan, and has been followed in the tentative formulæ (6) and (7). By it the working load is made a definite fraction of the load at which the column, as a whole, ceases to be perfectly elastic. As we have before said, the margin between this elastic limit of the column and its failing point may vary enormously for different proportions of columns.

Fourthly, comparing hinged and fixed-end columns, we see that the strength of hinged columns may be expected to be much more variable even than that of those with fixed ends, because it depends on two variable elements a and δ_0, while the fixed end gets rid of a. For a hinged column accurately centered $a_0 = 0$, and $a = \pm\ h \sin \phi$ being opposite in sign to δ_0, unless the hinge were very small indeed, b and c would then be negative. The meaning of this is that the friction would never rise to its limiting value, and the column would behave exactly as if its ends were fixed. The moment at the end of a fixed column under a load p is nearly $p \frac{\delta_0}{2} \left\{1 + \frac{p}{40\,E} \left(\frac{l}{\rho}\right)^2\right\}$, and while p is within the elastic load, the moment of friction in a hinge of ordinary size will be greater than this. When p reaches such a magnitude that the friction is not sufficient to resist rotation, we may expect the column suddenly to spring into a new position of equilibrium.

We see, then, that according to formula (5) an accurately centered pinned column will safely bear as great a load as if its ends were fixed, and would be much weaker if it rested on knife edges. It is possible, however, that in structures the vibration which usually accompanies increase of load may destroy the friction to a great extent, and, if so, it would largely diminish the strength we might otherwise allow for in pinned columns well centered, and besides that a_0 may in practice have a very appreciable value.

The above conclusions, which are strictly deduced from our investigation, agree in general with the observations made by Mr. Christie on his experiments referred to above.

At first sight it might seem an objection to formula (5) that when $\frac{l}{\rho}$ becomes very small p does not approach the value f as a limit, but a definite quantity less than f. A little consideration, however, will

show that any theory which takes into account the variations from ideal conditions on which the flexure of columns really depends ought to give that result. It must be remembered that f is not the safe load per sq. in. on a short column uniformly loaded, but the stress per sq. in. in the extreme fibres, and this will always be greater than the average stress, except under the ideal conditions of a and δ_0 being zero, which lead to Euler's theory.

The formulæ hitherto used to express the strength of columns have been empirical, that is, have been framed so as to agree as nearly as possible with the results of experiments. One of them has practically displaced all others, and is known as Gordon's formula, having been first made widely known by Professor Lewis Gordon, although it was put forward originally by Tredgold. Using the same symbols as hitherto it is as follows:

$$p = \frac{f}{1 + c\left(\frac{l}{\rho}\right)^2}$$

[and is sometimes given in a less correct form as:

$$p = \frac{f}{1 + c\left(\frac{l}{r}\right)^2} \quad]$$

We see that for columns of similar section in which $\frac{r}{\rho}$ is the same, this is practically the same formula as (5), for the second term in the denominator of (5) could then be got rid of by using a different value for f, viz.: $\frac{f}{1 + b\left(\frac{r}{\rho}\right)^2}$, the safe load per square inch on a short column of the section in question. It may be regarded as a confirmation of the truth of the principles on which we have proceeded that we have arrived at a similar formula in the main to that which is usually accepted as the nearest possible expression of experimental results. The agreement of Gordon's formula with experiments on the destruction of columns is, however, only comparative, and, as we have pointed out, could only be expected to be so. It would appear *a priori* that the introduction of $\left(\frac{r}{\rho}\right)^2$ into Gordon's formula, or some similar correction, ought to be an improvement, because, of two sections having an equal radius of gyration, that one with a smaller external diameter would have a higher elastic limit per square inch. The

results of experiments also have shown that Gordon's formula requires a different value of c for different sections of column.

In designing a column it is clear that, according to formula (5), a given cross-section A will give the greatest strength: first, when $\frac{A}{\rho^2}$ is as small as possible; secondly, when $\left(\frac{r}{\rho}\right)^2$ is as small as possible. We therefore give a table of the values of $\frac{A}{\rho^2}$ and $\left(\frac{r}{\rho}\right)^2$ for some simple forms of cross-section.

Form of Cross-section.	Plane of flexure.	$\frac{A}{\rho^2}$	$\left(\frac{r}{\rho}\right)^2$
1. Solid circular.....	Immaterial.....	4π or 12·5	4
2. Solid square.....	Bisecting sides...	12	3
3. do do	Through diagonal	12	6
4. Hollow circular (thin shell of radius r and thickness d).....	Immaterial.....	$\frac{8\pi^2 d^2}{A}\left(\text{or } 79\frac{d^2}{A}\right)$ or $\frac{2A}{r^2}$	2
5. Hollow square (thin shell of side $2a$ and thickness d).....	Bisecting sides...	$\frac{96d^2}{A}$ or $\frac{3A}{2a^2}$	$\frac{1}{2}$
6. do do	Through diagonal	$\frac{96d^2}{A}$ or $\frac{3A}{2a^2}$	3
7. Square, side $2a$, in which material is concentrated in the four angular points.....	Bisecting sides...	$\frac{A}{a^2}$	1
8. do do	Through diagonal	$\frac{A}{a^2}$	2
9. Square, side $2a$, in which material is concentrated along two opposite sides of thickness d.....	Bisecting closed sides.....	$\frac{16d^2}{A}$ or $\frac{A}{a^2}$	1
10. do do	Bisecting open sides.	$\frac{48d^2}{A}$ or $\frac{3A}{a^2}$	3
11. do do	Through diagonal	$\frac{24d^2}{A}$ or $\frac{3A}{2a^2}$	3
12. Angle bar, side a, (small) thickness d..	Through root of angle	$\frac{24A}{a^2}$	3

Nos. 7 and 9 are the ultimate forms of built up square columns with four sides latticed and with two plated and two latticed respectively. It appears doubtful, as was said before, however, how far the flexure of built up columns can be expected to follow the same laws as those of solid columns.

The table contradicts common impressions in one or two respects. It is commonly supposed that a square column is weakest for flexure in a plane bisecting its sides, but, since the moment of inertia of the cross-section is the same for all axes, the moment of resistance for a given curvature will be the same for all planes of flexure, and accidental circumstances will determine the plane in which flexure actually occurs. For a plane through a diagonal of the square, however, $\left(\frac{r}{\rho}\right)^2$ is twice as great as for a plane bisecting the sides, and therefore the diagonal plane is the one in which the column would soonest reach its limit of elasticity. For this plane a solid square column is therefore weaker than a solid circular column of equal length and weight, while, if the plane of flexure bisecting the sides of the square were alone regarded, the square column would be the stronger, ρ being almost the same for both. If hollow square and circular shells be compared, similar remarks apply, only in this case the circle has the advantage also of a larger radius of gyration nearly in the ratio of ten-ninths. If square columns of equal length and weight be compared, in which the material is in the first case distributed in a uniform shell, in the second along two sides of the square only, and in the third concentrated in the four angular points only, and taking for each case the most unfavorable plane of flexure $\frac{A}{\rho^2}$ varies in the three cases as 3 : 6 : 2 and $\left(\frac{r}{\rho}\right)^2$ as 3 : 3 : 2, showing that the last form has a considerable advantage in both respects over the others, and that the fully closed square is more economical than that latticed on two faces.

DISCUSSION.

Prof. Collignon

Professor Collignon said he did not propose to discuss Mr. Findlay's calculations in detail, but would refer to a pamphlet on the subject which he himself had written in January, 1889, and which seemed to throw some light on the question of struts loaded at the ends.

It at least shows that the indeterminate result of the analytic solution of the problem is due to the approximate method employed in solving the equations, and that it will disappear when the solution is more complete and rigourous. He would also beg to remark that the theory of struts loaded at the ends does not, in his opinion, aim at determining what takes place when the strut bends and is going to break, but rather at investigating the conditions which it must satisfy in order that it may neither tend to bend nor break. Engineers are nowadays very nearly in accord on this last practical question, and the formulæ which they employ, very different according to the country and customs, lead to the same results, excepting as to the degree of safety adopted.

Prof. Burr.

The subject of long columns has probably received as much analytical consideration as any one construction with which the engineer has to deal, and yet it is a little singular that most of the latest purely mathematical treatments of this problem are radically in error in the assumptions on which the mathematics of the subject are based. Unless the writer quite misapprehends its scope, this paper is not an exception to the last observation. Euler and the eminent mechanicians from his time down to the present, with Saint Venant and Clebsch pre-eminent among the later ones, saw and promised that the common theory of flexure could only be applied with even approximate accuracy to columns whose lengths were very great as compared with their lateral dimensions in the plane of flexure. Just what these lengths are it is perhaps impossible to exactly determine, but we know that with wrought iron, for which the coefficient of elasticity in compression may be taken at 28,000,000 lbs., and the ultimate resistance to compression in short locks at 60,000 lbs., the lengths will considerably exceed 140 and 70 times the radius of gyration for fixed and rounded ends, respectively, thus excluding the greater part or all of the columns used in railroad bridges. In fact a considerable number of Mr. Christie's tests of very

long angle iron struts indicate with strong probability that these limits should not be taken lower than 250 and 125 times the radius of gyration, which would leave nothing in the field of bridge columns to be even approximately covered by the theory. Such experimental results constitute by the process of exclusion a most interesting confirmation of the common theory of flexure in its own proper field, but demonstrate the hopeless futility of any and all attempts to force from it a column formula for bridge members. This erroneous impression regarding the applicability of the common theory of flexure to ordinary compression members is probably due to the fact that, with one or two exceptions only, writers of authority in the English language assume either the theory itself, or such imaginary and erroneous conditions as enable some of its chief features to flow from them in a very simple manner, and thus utterly fail to discover its true scope. If the theory were deduced from the fundamental conceptions of the mathematical theory of elasticity in solid bodies, as it should be, engineering authorities would fall into much fewer errors regarding its use, and, among others, the statement that it requires normal sections plane before flexure to remain plane during flexure. The theory shows, in fact, that such sections, in the general case, cannot possibly remain plane when flexure takes place.

But, returning to Mr. Findlay's paper, the writer thinks that it will impress most experienced structural engineers that his assumption of the eccentricity (a) of the line of applied load is very far, in most cases, from representing actual column conditions. If the columns are with flat ends, it is scarcely probable, and much less possible, that the line joining centres of pressure at their ends will be exactly parallel to its axis. In fact those centres are as liable to lie on opposite sides of the column axis as to occupy other positions, if not far more so. If the columns are with pin ends the assumption of a mean eccentricity of appreciable value is still more liable to be erroneous, for the centres of pressure are then essentially, if not exactly, at the pin centres in the column axis at each end. The matter of pin friction is too indeterminate to make it other than dangerous to attempt to definitely represent it in an analytical column formula, either by means of eccentricity or otherwise. These considerations in connection with the rough analytical approximations, by which Mr. Findlay causes a and δ_0 to be displaced by measurable elements, make it a matter of very serious doubt whether his formulæ are as exact, in the end, as theoretical expressions, as Euler's. The assumption of a mean value of eccentricities conduces to simplicity in analytical treatment, and is certainly justifiable on that ground; but

there is equally good reason for going a short step further and making the "mean value" zero, as is done in Euler's formula. In reality, as Mr. Findlay observes, his formula is in no way different from Euler's, except in the fact that the latter makes the former's a equal to zero. Hence the main features of both expressions, as column formulæ, must be essentially the same, and as it has been shown that both involve about the same degree of approximation, it is reasonable to conclude that neither will, on the whole, give actual column resistances much nearer than the other. This conclusion is confirmed by results of tests on full-sized columns.

These latter also confirm the conclusion reached in this discussion as to the impossibility of establishing any column formula for ordinary bridge members by the use of the common theory of flexure.

In 1879 Messrs. Clarke, Reeves & Co. tested to destruction sixteen full sized Phœnix Columns with flat ends, in the large testing machine at the U. S. Arsenal at Watertown, Mass. Each of these columns had a sectional area of a little over 12 square inches, and their lengths varied from 7 to 28 feet. Between the values of 28 and 112 for the ratio of $l \div r$ (length divided by radius of gyration) the following simple formula gives values of the ultimate resistance in pounds per square inch far more closely than any form of expression that can be deduced from the common theory of flexure:

$$p = 39640 - 46\frac{l}{r} \qquad (1)$$

It is believed that this experimental form of column formula was first given by the writer in a discussion of these tests, as published in the Transactions of the American Society of Civil Engineers for 1881. It has since come into quite common use.

During the years 1880, 1881, etc., a series of 70 tests of full sized latticed channel columns was completed at the U. S. Arsenal at Watertown, Mass., and the results were published in various "Ex. Docs." by the U. S. Government. These columns had $3\frac{1}{2}$ inch pin ends with 6 to 12 inch channels having areas from 4.65 square inches to 21.00 square inches, and lengths from 10 feet to 30 feet. Between values of 30 and 130 for $l \div r$ the formula:

$$p = 40{,}000 - 110\,\frac{l}{r} \qquad (2)$$

gives ultimate resistance in pounds per square inch nearer to the test results than any formula derived from the theory of flexure, although

the following is tolerably satisfactory :

$$p = \frac{36{,}000}{1 + \frac{1}{30{,}000}\left(\frac{l}{r}\right)^2} \qquad (3)$$

Three inch square solid wrought iron columns, varying in length from 30 to 179.5 inches, and tested in the same machine, with $1\frac{1}{2}$ inch pin ends, yielded the following very close formula between $l \div r = 30$ and 210 :—

$$p = 32{,}000 - 80\frac{l}{r} \qquad (4)$$

The full sized tests by Mr. James Christie, mentioned by Mr. Findlay, gave the following very close expressions for ultimate resistances in pounds per square inch :—

Flat and fixed end iron angles and Tees :—

$$p = 44{,}000 - 140\frac{l}{r} \qquad (5)$$

Round end iron angles and Tees :—

$$p = 46{,}000 - 175\frac{l}{r} \qquad (6)$$

Flat end mild steel angles :—

$$p = 52{,}000 - 180\frac{l}{r} \qquad (7)$$

Flat end high steel angles :—

$$p = 76{,}000 - 290\frac{l}{r} \qquad (8)$$

Equations (5), (6), (7) and (8) are to be used only between $\frac{l}{r} = 40$ and 200.

Flat end iron channels and I beams for $\frac{l}{r} = 20$ to 240 :—

$$p = 40{,}000 - 110\frac{l}{r} \qquad (9)$$

It has not been thought necessary to reproduce here either the mass of numerical results showing a comparison between the experimental resistances and those derived from Equations (1) to (9), or the scale diagrams showing the same thing, but they may be seen in all detail and consulted in the writer's "Resistance of Materials," pages 450 to 462.

None of the above Equations except Equation (3) can be established either in form or type by the common theory of flexure, nor does Equa-

tion (3) or any other formula similar to it or to Euler's give results agreeing nearly as well, with full sized tests, as those of the above equations between the limits indicated, which, it is important to observe, are both below the theoretical limits of applicability of Euler's formula. The crucial test of actual experience, therefore, shows only what the true theory establishes with equal clearness and certainty, viz., that no formula based on the common theory of flexure can be devised which will satisfactorily represent the ultimate resistances of ordinary bridge columns.

Mr Moulton. Having carefully followed Mr. Findlay's demonstration of the formula he presents for the permissible stress in columns, it seems to the writer that he has produced one which gives proper expression to the factors which should be recognised and used as the basis of working data in proportioning structures.

The main trouble, however, is, as he clearly states, that experimenters have not given us sufficiently complete data, in the reports of their tests, to enable us to judge accurately when in the tests the elastic limit was passed, and at what points actual crippling of the piece as a whole occurred.

The writer has never doubted that if we could determine with certainty, in compressive tests on columns, the stage at which the elastic limit is passed, it would be found to vary with much more regularity than that at which crippling takes place.

Could we have a sufficient number of reliable experiments, conducted according to a proper system, and covering the ordinary range of lengths and forms of cross section, so as to obtain the elastic limit for each case in a similar manner, there would result much more rational data from which to determine our working values than those on which our present formulæ are based.

There is, however, little likelihood of such experimental work being done for some time, hence the question arises whether we can improve our formulæ with our present data.

For determining the modulus of elasticity of a built column, the best way would of course be to test one like it, otherwise we must determine the compressive moduli of the component parts, either by direct compressive tests, requiring much care in preparation, or by approximations from the tension moduli, and assume that the resultant is like that of the whole column.

The writer has little faith in the latter method, as he has seen, in steel, so much variation in the modulii of the parts composing a

certain built member, and has also observed, in the case of a very few steel posts, where he has had accurate data for comparison, the further variation of these modulii from that of the post as a whole.

If we could refer our permissible stress to the elastic limit, the factor or ratio would be, of course, much less than we now use when referring to the ultimate crushing strength, and consequently we should have to deal very carefully with the circumstances tending to vary the elastic limit.

Mr. Findlay makes an excellent point when he introduces the factor $\left(\frac{r}{\rho}\right)^2$ into his formula, and were Gordon's (or Rankine's) a more rational formula, the writer would agree that it would be well to introduce it there; but, as far as our practice in the United States is concerned, the tendency is to forsake the formula as it stands for simpler forms which represent straight lines, and seem to fit in between the experiments about as well, and any further complication or rather addition to the formula would be about as hard to introduce with us as an entirely new formula.

The disturbing element in railroad structures, which has always seemed to the writer to tend to vitiate any deductions drawn from quiescent tests in the physical laboratory, is the vibration during the passage of rapidly moving loads.

We are of course trying to arrange our formulæ to take account of this, but when we get down to bottom facts what have we for data on which to base our changes?

Fresh in mind is a discussion on a set of formulæ presented to the Am. Soc. C. E., which embodied the ideas brought out by the experiments of Wöhler and Spangenburg; and it was argued, and the writer thinks maintained, by the majority of our most prominent experts, that the experiments and the data afforded by them were not sufficient to warrant us in accepting and applying the theory in the form then presented.

Such being the case with a long series of experiments in evidence, how little direct and conclusive testimony may we be said to have regarding the effect of vibration on the resistance of the compression members in a railroad bridge? None attempt to ignore its influence, and the theory most accepted with us now is to make the permissible working stress for live loads equal to one half that for dead loads. Necessarily, there must be a starting point for the formulæ, and that is taken so that the old units obtain for a structure wherein the dead load is about one half the live load. This would occur with the American type of construction in a span of about 150 feet single track, with a live load

of two consolidation engines each weighing about 83 net tons on 50 feet, followed by a train of 3000 lbs. per lineal foot.

The first advance was in using Rankine's formula expressed in the present paper

$$p = \frac{f}{1 + c\left(\frac{l}{\rho}\right)^2}$$

in which the constant "c" varied with the form of section as before, and the constant "f" was made 8000 lbs., increased in a certain ratio as the span exceeded 150 feet—all applied to the combined live and dead stresses.

As before mentioned, the form most in present favour is a formula of a straight line, and is applied to the live and dead load stresses separately, giving the permissible unit stresses for the former just one half of those for the latter.

The writer has preferred to retain the "Rankine" form, giving as it does a somewhat greater range, varying the constant "f" in a similar manner for live and dead loads separately, and has found it quite acceptable to a number of engineers of prominence.

It is his belief that the next move in experimental work of value, to determine the working strength of columns, will have to be made by applying some form of self-registering dynamometer to columns in existing bridges during the passage of trains, and by systematic experiment with known loads and velocities ascertain what our compression members already constructed and in constant use are doing under their daily conditions, and from such data, together with full knowledge of the parts when unloaded, ascertain the state of our practice in designing columns, and wherein it should be improved.

Mr. Whited. The author speaks of Euler's theory of columns as being unsound. It is a fact that a long column shows no notable deflection until it is loaded very nearly up to its ultimate strength, and although it may be difficult to understand how the same load that first produces flexure is sufficient to bend the column double, experience shows that the increase of load necessary is slight, and it is quite possible that that slight increment may be accounted for by the internal stresses, the want of uniformity, and the eccentricity of the column.

He also says that the length of a wrought iron column must be about 100 times its radius of gyration in order that it may fail by bending under a load equal to its elastic limit, and about 140 times its radius of

gyration—not 400 times, as the author states—in order that it may fail under $\frac{1}{2}$ its elastic limit according to Euler's theory, while columns much shorter than this actually do fail by bending. These facts may be accounted for by the fact, that some portion of the shorter column is strained beyond the elastic limit before Euler's limit is reached, and therefore no rational theory will hold, and experiments prove very little. It may be assumed that whenever any portion of a column is strained beyond its elastic limit, bending will take place provided $\frac{l}{s}$ exceeds a certain very moderate amount. Euler's theory is based upon conditions that are not realized in practice, but that is the case with a great many other physical theories.

With regard to the values of f and c, they seem to depend very much upon circumstances, and that the engineer has an excellent chance to use a little good judgment in his assumptions. For example, rolled wrought iron is made sometimes from special and sometimes from miscellaneous scrap, but in any case it is liable to be far from uniform. Mild steel is rolled from the ingot, and is much more nearly homogeneous. Cast iron is very liable to hidden defects, and allowance must be made for that fact. The closing of the rivets in rivetted columns is liable to produce quite serious internal stresses, the cold straightening of rolled metal has a similar effect. In columns for buildings the settlement or yielding of something may change the manner of loading very materially. Such things as connecting rods and other working parts of machinery that are machined all over are much more accurately made and loaded than any class of structural iron work. In bridges the speaker is in favour of specifying a certain maximum eccentricity, perhaps about one-half inch for ordinary bridge work, and insisting upon that rule being observed. To be sure some engineers specify that compression members for bridges shall be perfectly straight, but any manufacturer will tell them that he does not expect to make anything perfect in his establishment until the millennium. If engineers will bear this fact in mind, and write specifications that can be carried out at a price they are willing to pay, insist on their being strictly carried out, and make their calculations accordingly, substituting the corresponding values for the constants in the author's modification of Euler's formula, making due allowance for accidental circumstances, they will have their columns as well proportioned as the present state of science and art will permit in all cases where the author's formula is available.

The speaker's experimental knowledge of columns is very limited, but the tests that have been carried out were very carefully made with

the Emery testing machine, and the results were as follows:—

TEST NO. 1.

$3\frac{1}{8}$ " × $3\frac{1}{8}$" × $\frac{1}{4}$" I beam, square ends 86.3" long, deflections measured from points 84" apart. Area 2.448 sq. in., moment of inertia 1.3604, radius of gyration .7455", $\frac{l}{\rho} = 116$ failed at 91100 = 37214 per sq. in. Elastic limit in tension 41356 per sq. in., so that in view of the fact that the elastic limit in tension may differ considerably from that in compression, and also owing to various causes mentioned above, the stress may not have been uniformly distributed over the section of the column, and it is fair to assume that some part of the column was strained beyond the elastic limit before failure took place, and therefore no column formula has any legitimate application. When the load reached 53,000 it was removed, showing no permanent compression and very slight permanent deflection, and the deflection did not reach its previous amount until the load reached 88,000, and was not notably increased till the load was within 1 per cent. of the ultimate strength, and after the ultimate strength was reached the load diminished while the column continued to deflect. This was owing of course to the outer fibres being strained beyond the elastic limit.

TEST NO. 2.

$5\frac{1}{8}$" × $4\frac{3}{4}$" I beam, 112.26" long square ends, deflections measured from points 108" apart. Area = 4.854 sq. in., moment of inertia = 4.97074, radius of gyration 1.0119". This was tested transversely on 35" bearers with the load in the centre showing a deflection of .0265" at 5390, whence, by the equation of the elastic curve, the modulus of elasticity = 36630000. This column did not fail under the greatest load the machine was capable of applying, and is only given to show how rapidly the deflection takes place as the ultimate strength is approached. It was not so rapid in this case as in the preceding one, doubtless owing to internal strains in the metal. It will also be seen that the column was strained very little beyond its elastic limit.

TEST NO. 3.

Another piece of the same I beam from which 2 was cut. This was tested on pin bearings, pins 2.92", length centre to centre 111.17", $\frac{l}{\rho}$ about 110; failed at 149600 by crippling. The diagram shewed that the deflection was almost *nil* until the load had nearly reached

the maximum, when it increased very rapidly, in the present case with a bound, probably because the friction of motion on the pin was less than the friction of rest. If we substitute the value of the modulus of elasticity as given above = 36630000 in Euler's formula, we shall obtain 145100 as the ultimate strength of the column, which agrees sufficiently nearly with the experimental result. It is to be understood, however, that this fact does not prove Euler's theory to be applicable in practice, it only tends to indicate that the conditions of the test were very nearly those on which Euler's theory depends.

Thursday, 27th March.

H. T. Bovey, Member of Council, in the Chair.

The discussion of Mr. M. J. Butler's paper on "The Manufacture of Natural Cement" and of Mr. Findlay's paper on "Columns" occupied the evening.

Thursday, 10th April.

C. E. Goad, Member, in the Chair.

The following candidates having been balloted for were declared duly elected as:—

Members.

Ira Abbott, Alexander Lauder Hogg.

Associate Members.

Arthur Thomas Kelly Evans, Charles Thomas Symmes.

Associates.

Walter Reginald Baker, Hon. Donald McInness,
J. Philip Scott.

Students.

Franklin M. Bowman, Henry Robertson Lordly,
John Andrew Duff, James R. Pedder,
Joseph H. Lefebvre, Thomas Henry Wiggins.

The following has been transferred from the class of Associate Members to that of Members:—

Charles Le Baron Miles.

The following has been transferred from the class of Associates to that of Associate Members:—

George Brokitt Abrey.

The following has been transferred from the class of Students to that of Associate Members:

Roderick MacColl.

IRRIGATION IN BRITISH COLUMBIA.

By E. Mohun, M. Can. Soc. C. E.

The art of irrigation may claim to have been practised by the oldest branch of that profession which seeks to direct the great sources of power in nature for the use and convenience of man. Its origin is lost in the mists of antiquity, but the skill and knowledge of hydraulic laws possessed by the first civil engineers are attested by the ruins of the gigantic works constructed by them in Egypt and Assyria. In the former we find the artificial Lake Mœris, two hundred and twenty-five miles in circumference, according to Herodotus, supposed to have been constructed by Amenemhat III. about 2380 B.C., the great Canal Bahr-Yoosup, 350 miles long, constructed under the Pharaohs, and repaired by Saladin, and the Sweet Water Canal attributed to Sesostris about 1400 B.C. In Assyria, Khammuragas, probably about 2000 B.C., is credited with the construction of numerous canals and the embankment of the Tigris.

About 600 B.C. Nebuchadnezzar embanked the Euphrates; cut canals to carry its overflow into the Tigris; excavated a reservoir, forty miles square and thirty-five feet deep (Herodotus) to receive the waters of the former river, while its channel was being lined with brick; and constructed the far-famed Hanging Gardens of Babylon, on a series of arches at least 75 feet high and 400 Greek feet square. It is said that the water for their irrigation was raised from the Euphrates by an Archimedean screw. In China its history appears to be coeval with that of the Chinese Empire. In India in modern times the Imperial Government spent in ten years on irrigation no less a sum than £10,457,702 sterling. Of this amount £5,673,401 was expended in the North West Provinces, including the great works of the Ganges, the Eastern Jumna, the Agra, and the Lower Ganges canals; the area irrigated in the North West Provinces being 1,461,428 acres.

One of the most gigantic of modern irrigation schemes is proposed in Southern Idaho, and includes the construction of two great canals 300 and 280 miles long respectively, for the purpose of irrigating an estimated area of 4,500,000 acres. At the present day irrigation is in systematic use on every continent, and has proved of inestimable value in adding to the food supplies of the population of the globe.

In 1878 the author received instructions to report upon irrigation as-

practised in British Columbia for the information of the Dominion Government, and this paper is principally based upon the notes then taken. He would also bespeak the indulgence of the older members, when entering into details with which they are familiar, but to which, it may reasonably be assumed, some of the younger members have not probably devoted much attention. The main objects of the investigation were to ascertain how much water was required for crops, and whether the existing supplies were properly utilized.

THE MINER'S INCH.

As there will be frequent occasion to refer to the Miner's Inch, the standard measure of water both for mining and agriculture, it may be well before proceeding further to define it.

In California, the inch varies in different localities, and it means the amount which will pass through an orifice one inch square in a two inch plank with a certain head; the usual head is six inches above the top of the orifice. As, however, the depth of the orifice is sometimes made two inches, with a head varying from five to eight inches above it, it is obvious that the inch in California is not a fixed quantity in practice, and the writer believes there is no State law regulating it. Mr. Melville Attwood, a well-known mining engineer in San Francisco, informed the author that the inch recognized by the profession generally was 92 lbs. a minute. About sixteen years ago Mr. Amos Bowman, now of the Geological Survey of Canada, then in California, made a practical and admirable suggestion, namely, that an inch of water should mean 100 cubic feet an hour, or 2400 cubic feet a day. Had his suggestion been adopted, the matter would have been much simplified.

In 1878 the Mining Laws of British Columbia permitted the orifice to be ten inches or less in depth, with any head not more than seventeen inches above the *bottom* of the orifice. A few years later the author brought the matter to the notice of the Provincial Government; the following is now the definition according to the Land Act:—

"In measuring water in any ditch or sluice, the following rules shall be observed:—

"The water taken into a ditch or sluice shall be measured at the ditch or sluice head. No water shall be taken into a ditch or sluice except in a trough placed horizontally at the place at which the water enters it, and which trough shall be extended two feet beyond the orifice for the discharge of the water. One inch of water, or any multiple of one inch, shall mean half the quantity that will pass through an

orifice two inches high by one or more inches wide, with a constant head of seven inches above the upper side of the orifice."

These dimensions and head were adopted as being as nearly as possible in accordance with the customary measurement. It is believed that this standard has since been adopted by the Dominion Government.

Taking the value of c. at 0.645 (Greenhill & Unwin):—
one inch $= 0.645 \sqrt{29h} \times 0.01389 \times 43200 = 2536$ cubic feet a day.
And for orifice of different depths with other heads the number of inches $= C\sqrt{h} \times 273.4 \times a$.

The construction of gauges has for a long time occupied the attention of the hydraulic engineers of Northern Italy; and the researches and experiments made by them, for the purpose of establishing a simple self-acting instrument of that description, led to the discovery of the following curious law of hydrodynamics, upon which is based the principle of the gauges used in Piedmont and Lombardy.

"It was ascertained that, in a vase constantly supplied, but divided into two portions by a diaphragm susceptible of being moved vertically, with a discharging orifice on one side of the vase, a constant difference of level existed in the surfaces of the respective portions of the reservoir so long as the water flowed; and that this difference of level was greater in proportion as the opening of the diaphragm was less compared to that of the orifice. And it was also observed that if, by any change in the direction of the supply or the flow, the level were made to alter on either side of the diaphragm, the corresponding variations in the level upon the two sides continued always to be proportional to the respective difference of level first established." (Burnell.)

A sketch of one of these modules is shewn in Plate VII, Figure 1, in which the water is admitted into the regulating chamber A by the movable sluice b. The water is maintained at the proper height in the regulating chamber when discharging through the orifice O, by raising or lowering the sluice b. The chamber A is covered with a ceiling at the exact level of the required head (which is indicated by a gauge) to still the agitation of the entering water. The unit of measurement varies in different localities as follows:—

	Height of Orifice. ft.	Width of Orifice. ft.	Head above top of Orifice. ft.	Discharge i cubic feet a second.
Canal Lodi.....	1.12	0.12416	0.32	0.61655
Canal of Cremona.	1.31816	0.131	0.131	0.722
Sardinian Module.	0.6562	0.6562	0.6562	2.046
Oncia Magistrale of Milan.....	0.655	0.3426	0.3294	0.866

In Spain a module giving very good results is in use on the Madrid Canal, Figure 2. Its construction, however, involves a serious loss of level between the canal and the irrigation ditch. This module consists of two chambers, one above the other. To the upper one the water has free access from the canal, in its floor, which is also the roof of the lower chamber; there is a circular sharp-edged orifice in a bronze plate, in which hangs a circular plug of varying diameter suspended from a float. The plug is so shaped that as the water in the upper chamber rises and falls and the float and plug with it, the free passage in the orifice is diminished or enlarged, so that the quantity discharged is uniform, though the head may vary. From the lower chamber the water is discharged through a culvert into the irrigation ditch.

An ingenious method of measurement has been proposed in England. In this module the orifices are in a sliding metal plate, connected by a link to a lever, attached at one end to a float in the regulating chamber, and so proportioned that the plate rises and falls with the float, maintaining the top of the orifice at a uniform depth below the surface of the water. Mr. Appold has also invented a module in which the water passes through a pipe having an enlarged chamber, in which swings a heavy pendulum, so proportioned that the discharging orifice diminishes as the pendulum under increased pressure approaches a horizontal position.

The general rules for irrigating crops, laid down by DeCandolle, are thus briefly enumerated by Dempsey:—

1st. That the water should be well aerated; the presence of atmospheric air is good, but that of carbonic acid gas much better; and it is desirable that the water should contain fertilizing matters.

2nd. In the winter there should be little irrigation, because the plants are then dormant, and water is then superabundant. In spring water is usually abundant. In summer it is wanting; and at that time the water should be given in the evening.

3rd. The quantity of the water to be applied should be varied according

a. To the object of the culture:—When for leaves, more water should be given than when for flowers; less water should be given when for grains or fruits.

b. To the depths of the roots:—The application should be more frequent to the plants of which the roots are superficial; less frequent to deeper roots.

c. To the structure of the foliage:—Those which evaporate much (such as plants with large leaves) more frequently than perennial, or plants with thick leaves.

d. To the consistence of the stalks and of the roots:—Roots with fleshy fibres do not thrive if too abundantly watered; at the same time they are injured by dryness. Tuberculous or bulbous plants, or plants with fleshy leaves, can bear a long-continued dryness, and therefore infrequent, yet abundant, watering suits them well.

e. To the stage of vegetation:—It is important to bear in mind that young germinating plants require light and frequent waterings; those that are in the height of growth abundant waterings; and when the fruit or seed is being matured the waterings should be infrequent.

Those that have been transplanted require abundant watering.

f. To the nature of the soil, according to which the rules must be modified:—The lighter the soil the more frequent and plentiful must be the waterings. If it is a compact and clayey soil, less watering will be required.

g. To the state of the atmosphere:—It will be readily conceived that the watering must be more frequent when the temperature is high, the sky clear, and the air dry, and during drought.

Quantities necessary in Europe, Africa and Asia.

In connection with the subject it will be well to consider the quantities estimated to be necessary in different localities, when irrigation on an extensive scale is carried on; and Mr. Burnell gives the following figures:

Grau d'Arles.....	932	cubic	feet	per	acre	a	day.
Haute Garonne.....	622	"	"	"	"	"	"
Algeria.....	244	"	"	"	"	"	"
Eastern Pyrenees.....	205	"	"	"	"	"	"
East Indies.....	400	"	"	"	"	"	"
South of France.....	1200	"	"	"	"	"	"

The first and last of these quantities Mr. Burnell (and probably the reader will agree with him) considers excessive. He also states that the successful cultivation of rice is estimated to require 1440 cubic feet a day; but as rice is an essentially aquatic plant, requiring to be constantly immersed in water during its growth, while it cannot be cultivated with success north of the 46th parallel, its irrigation need not now be taken into consideration.

In that part of the Sahara which is contiguous to the French possessions in North Africa, much has been done in the way of irrigation, during the last few years, by means of artesian wells. Throughout the low-lying portions of the Algerian Sahara, there appears to be

an abundance of subterranean waters, which only require an outlet to the surface to cause the wilderness to blossom as the rose. The first French well was bored in 1856, which yielded about 82 inches; and by the 1st October, 1885, there were in the Oned Rir, a valley about one hundred and twenty miles long, one hundred and fourteen artesian wells, and four hundred and ninety-two natural springs, yielding about 5,100 inches. Nor has this large flow affected the yield of the older wells. The "Société de Batna et du Sud Algerien," formed in 1881, in the first five years of its existence, sank seven wells yielding 527 inches, reclaimed one thousand acres of desert, planted more than fifty thousand date palms, constructed twenty-five miles of irrigation ditches, and built houses for the cultivators and company's agents, and have already derived a revenue in round numbers of $100,000. (Chambers' Journal.)

SYSTEMS OF IRRIGATION.

In Lombardy the bedwork system of irrigation is generally adopted, in which the land to be irrigated is thrown up into ridges, the more compact the soil the wider the ridge. On the summit of the ridge is the shallow feeder or floating trough, from which the water is shed over the gently sloping sides of the ridge. The usual dimensions of the floating troughs are about 20 inches wide at their junctions with the conductors, decreasing in width to about 12 inches at their lower ends, while they are generally about 70 yards long. The main conductor, from which the floating troughs are supplied, is usually but not necessarily at right angles to them, and the water is commonly turned off by closing the upper end of the floating trough with a sod. Between the ridges are small drains in which the superfluous water is collected and conveyed to a main drain, from which it is either again used to irrigate lower lying lands, or returned to the stream from which it was originally taken.

Figure 3 shews how with favourable natural contours a comparatively small amount of water can be of very considerable service.

In the Figure AA is the main conductor, BB the main drain, a a are the floating troughs, b b the drains, c c are either conductors or drains according to circumstances, D, E, F, G, H & L, being hatches or sluices for the direction of the water. It is obvious that by opening or closing the hatches as circumstances dictate, the whole or any portion of the water can be directed to any particular section, and the superfluous water from one division used upon a lower one. In mountainous

districts the main conductors have frequently a fall of 1 in 500; in the plains the fall usually is from 1 in 1500 to 1 in 3500.

In the catchwater system, extensively used in the water meadows of England, though generally considered inferior to the bed work, the water is conveyed along the side of a slope in a nearly level ditch without an outlet. As soon as the ditch is full, its contents begin to flow over the lower bank; at distances of about 30 feet, other level ditches on contour lines without outlets are formed, which collect and redistribute the water over the next lower area, when it is again caught and redistributed, until it finally reaches the lowest ditch, which is a drain.

A third method, that of sub-irrigation, has been employed both in England and in the United States, generally for the purpose of utilizing and disposing without offence of liquid sewage. It has been received with favour by some persons, and has been adopted on free soils with apparent success, but as the liquid is distributed through the subsoil by underground pipes which are out of sight, the process is liable to objections which sanitarians cannot fail to recognize and appreciate.

The foremost of these objections is the fact that the distributing pipes must sooner or later become choked with the minute solid matters held by the liquid refuse in suspension, and when this is the case an "excrement sodden" condition of soil is produced. A stoppage can only be detected by positive signs of wetness on the surface, and not until the evils produced by exhalations from excrementitious matter may have gained an ascendency. Mr. Rogers Field has done much to overcome these objections. The drains by which he effects the distribution of the liquid consist of common agricultural drain pipes, laid some 10 or 12 inches below the surface upon a continuous bed of larger half pipes. This bed is not disturbed when the pipes are taken up to be cleaned, which ensures their being readily re-laid in true position. The sewage flows out of the joints into the soil and feeds the vegetation, and the concentrations of the flow, effected by the sudden discharge of a regulator or flush tank, with which the pipes are connected, forces the liquid rapidly along them.

In deference, however, to the wide experience of Mr. Rogers Field, and to the practical results obtained by Mr. Waring of Newport, U. S. A., who has adopted this means of sewage utilization in various instances in America, it is only right to append an extract from one of this last-named gentleman's letters on this subject.

In it he says: "I am carrying out the principles of sewage util-

zation here to some extent, not, however, in surface irrigation, but in the distribution of screened sewage by means of flush tanks of larger capacity, and of sub-irrigation by draining tiles laid about 10 inches below the surface of the ground. Some of this work dates back to 1869, and in one instance I have disposed in this manner of the sewage of a village of about 1500 inhabitants, and in another of the outflow of a prison producing about 30,000 gallons per day.

"In every instance the result has been most satisfactory, and I have large works of the same character now on hand." (Bailey-Denton.)

The sub-irrigation of drained land is also accomplished by closing the outlets of the drains, when the surface becomes too dry, and thus holding back the water in the soil, a very convenient method in land which has been over-drained. This system is in use to a considerable extent in Switzerland, and has been common in Persia for a great length of time. A system of irrigation known in England as "warping" is common in many countries; under this the land is flooded with water, having a large amount of mineral substances in suspension, the water being retained upon the land until the fertilizing matter has been deposited.

In British Columbia it has not been found practicable in many instances, owing mainly to the high price of labour, to properly prepare the surface for the reception of the water, and it is obvious that were such preparations made, a smaller quantity of water than is now in such cases used would be required, as we more nearly approached to its most economical distribution. In this province neither the bedwork nor catchwater systems have been adopted in their integrity. The more general method in use appears to be derived from the former. The ground is frequently formed in narrow ridges, and the water is carried in the hollows between them, instead of as in the bedwork system proper on top of them, and finds its way to the higher portions of the ridge by capillary attraction, so that in effect the lower part of the ridge is watered by surface and the upper part by sub-irrigation; a curious example of a combination of different principles. The method, however, appears a successful one. Grass crops are generally flooded to a depth of a few inches at each period of irrigation; the depth varies, and depends mainly on the amount at the disposal of the agriculturist.

In California, where irrigation, under somewhat similar conditions of climate and soil as those which obtain in this province, has proved most successful, it is customary among the ditch companies to charge the farmer for one cubic foot of water a second,—34 inches,—for

each one hundred and sixty acres under cultivation, equivalent to 540 cubic feet per acre a day, or a monthly rainfall of 4½ inches, of which it is estimated that not more than about ⅓ is actually absorbed.

The managing director of a company, engaged in extensive irrigating operations, stated in answer to enquiry: "In the San Joaquin Valley in the beginning of the farming season, a furrow is turned up all round the track, thus forming a check, and the water is turned on until the land is so thoroughly saturated that it will absorb no more. This, with the few inches of rain that fall in the spring, is often enough to mature a crop of wheat, barley, etc. If not, then as the heads begin to fill out, that is six weeks or two months before maturity, the necessary amount of irrigation has to be applied."

It is obvious that such a method as this is only applicable to very level land. It is also to be remarked that there is no special irrigation season for grass in that state, the climate permitting this crop to be irrigated all the year round or nearly so.

Mr. Amos Bowman remarks as follows:

The quantity of water required to irrigate an acre varies considerably, depending chiefly upon the crop. Vines require very little; none after they are rooted. Other fruit requires irrigation. An inch of water running night and day will irrigate from one to ten acres for some products. For grass and clover, 10 inches, running three days in the week (of 24 hours each), would irrigate ten acres. Perhaps a constant flow of five inches to every ten acres would be near the mark, in other products one half an inch to the acre.

The few results obtained by the writer, as examples of the quantity of water required to irrigate an acre, may be stated as follows:

For hay, one inch to half an inch per acre, running night and day.

For berries and newly planted vines, one half to one quarter inch per acre, running night and day.

For trees, one quarter to one tenth of an inch per acre, running night and day.

About eleven years ago a Mr. Pike sank an artesian well in the San Joaquin Valley, 268 feet deep, which it is stated cost between $400 and $500. The flow from this well was estimated at about 18,000 cubic feet a day, between 7 and 8 inches, and it was claimed to have successfully irrigated about 10 acres of barley, 5 acres of wheat, 5 acres of English peas, 2 acres of Chinese sugar cane, 4 acres of oat hay, 1½ acres of corn, besides a small orchard and vegetable garden, in all say from 28 to 30 acres; or approximately that one inch irrigated

four acres of land. In California the extensive tracts of land which can be cultivated with the aid of irrigation encourage the formation by joint stock companies of irrigation ditches on too large a scale, and generally of too costly a character, to be undertaken by individuals.

Among them may be mentioned:

The Rodes Ditch.....	length	about	10	miles,	cost	about $10,000
Lower King's River Ditch.	"	"	13	"	"	" 28,000
Last Chance Ditch.....	"	"	20	"	"	" 60,000
Mussel Slough Ditch.....	"	"	60	"	"	" 60,000
The People's Ditch.....	"	"	45	"	"	" 100,000
The Settlers Ditch....	"	"	20	"	"	" 30,000
The Lake Side Ditch.....	"	"	30	"	"	" 50,000

The foregoing are some only of the larger ditches. Since the date at which these notes were taken several very costly ones have been constructed, of which the author cannot give any details. During the past ten or twelve years considerable additions to the water supply for agriculture in California have been obtained from artesian wells.

IRRIGATING DISTRICT OF BRITISH COLUMBIA.

The district in this province in which irrigation is required may be roughly described as the elevated plateau lying between the Cascades and the Rocky Mountains. It is broken by smaller mountain ranges and spurs from the main chains; its elevation varying from about 800 to 3000 feet above the sea. The soil of the benches and terraces and irregular slopes of some of the valleys, which were once probably the bed of a large lake, is extremely fertile when cultivated, and has been described as composed of modified or redistributed drift, modern alluvium, etc., and is chiefly the product of the disintegration and rearrangement of the boulder clay, though mixed also with the detritus from local rocks since the glacial period, which has been carried down by rivers, when flowing at a higher level as they seem here to have flowed in the past. (See Report Geol. Sur. of Canada.)

It appears that, at a greater elevation than about 2000 feet, summer frosts prevent successful cultivation as a general rule; though in some instances, owing to favourable local conditions, cultivation has proved remunerative of greater elevations. A curious instance of the uncertainty of obtaining a crop occurs at Douglas Lake, Nicola Valley; the Lake is 4 or 5 miles long at an elevation rather over 2000 feet, the soil at its head and foot appears identical, and the conditions seem precisely

similar, yet both Whites and Indians agree that the crops at the head of the Lake are very uncertain, while at the foot they rarely fail.

IRRIGATION ESSENTIAL.

It must be understood that in the section of country referred to, with a few notable exceptions, such as the Spellamcheen Valley, cultivation cannot be successfully carried on without irrigation. This is usually applied three or four times in the season, commencing in April, at intervals of from twenty to thirty days.

SOURCES OF SUPPLY.

The main stream of the Fraser and Thompson Rivers lie too far below the fertile benches in their valleys to render their boundless resources available except by pumping; this is unfortunate, for their waters contain an enormous amount of fertilizing matter in suspension. The principal supplies are derived from the smaller mountain streams, which generally attain their greatest volume in May, the month in the commencement of which the largest quantity is required; during the two succeeding months they fall very rapidly, and in dry summers there may be a scarcity towards the latter end of the irrigation season.

When it is practicable, to select from different sources of supply, which is rarely the case in British Columbia, the broad rule would appear, to be that the water which has been longest exposed to the air is the best for the purpose, and it is on this ground that it is advisable to construct the main conductors wide and shallow; and though this form leads to a greater loss by evaporation, it also diminishes to an appreciable extent the lateral pressure on the banks. Water from lakes and large streams is generally of such a temperature as to be permitted to run without cessation; but when obtained from cold springs and short snow-fed streams, it is sometimes necessary to shut it off during the night. Authorities on this subject appear to consider that the best water for irrigation is obtained from artesian wells of considerable depth, on account of its temperature, and also on account of the mineral elements usually contained in it.

The artesian wells of Dakota are, perhaps, the most remarkable examples of their kind which have ever been opened, both as regards the pressure and the volume of the escaping water. More than one hundred wells, from 500 feet to 1,600 feet deep, are at present in successful operation in the district north of Yankton, and they yield a constant stream of water which is apparently never affected by any

of the surrounding influences. The pressure of the water is abnormally high in many instances, and up to 180 lbs. per square inch has been registered by the gauges. (Industries.) Artesian wells have not yet been sunk in this province; the Provincial Government, however, last year commenced an experimental bore in the valley of the South Thompson River.

Mr. Bailey-Denton says:

In the "conclusions" arrived at by the "Rivers Pollution Commissioners," the average composition of "unpolluted waters" is given in the following form:

Results of analysis expressed in parts per 100,000.

Description.	Dissolved Matters.								Hardness.			No. of samples taken.
	Total solid impurities.	Organic Carbon.	Organic Nitrogen.	Ammonia.	Nitrogen as nitrites or nitrates.	Total combined nitrogen.	Previous sewage or animal contamination.	Chloride.	Temporary.	Permanent.	Total.	
Rain water	2.95	.070	.015	.029	.003	.042	42	.22	.4	.5	.3	39
Upland surface water.	9.67	.322	.032	.002	.009	.042	10	1.13	1.5	4.3	5.4	195
Deep well w't'r	43.78	.061	.018	.012	.495	.522	4,743	5.11	15.8	9.2	25.0	157
Spring water...	28.20	.056	.013	.001	.383	.396	3,559	2.49	11.0	7.5	18.5	198
Average	.....	.127	.019	.011	.222	.250	.....	2.24	.....	.....	.....	....

Without venturing to express an opinion upon the precise meaning of "previous sewage or animal contamination," the heading of one of the columns, these figures shew an exceptionally large amount of fertilizing matters in the waters from deep wells.

Temporary hardness is hardness due to calcic or magnesic carbonates, and can be got rid of by boiling the water. Permanent hardness is hardness due to calcic or magnesic sulphates, and cannot be got rid of by boiling. One grain of bicarbonate or sulphate of lime in a gallon of water is expressed as one degree of hardness per gallon.

It must not be inferred from previous remarks, that the table land of which we are speaking is badly watered for purposes other than those of irrigation. On the contrary, the whole surface of the country is dotted

with lakes and traversed by streams, varying in size from the Fraser River to the tiniest rivulet, though frequently, from their positions and the large outlay required before they can be utilized, they are practically excluded from being classed among the available sources of supply.

RAINFALL.

The following table shews the rainfall in the irrigating and non-irrigating districts of British Columbia, during the irrigation season of 1877.

IRRIGATING DISTRICT.

Place.	April.	May.	June.	July.	Total.
Spence's Bridge.....	0.38	1.41	0.75	1.25	3.79
Cache Creek.....	1.03	1.10	1.35	1.22	4.70
Kamloops.....	0.78	1.42	1.67	0.59	4.46
Okanagan	0.22	1.75	2.15	1.42	5.54

NON-IRRIGATING DISTRICT.

Place.	April.	May.	June.	July.	Total.
Spellamcheen.....	1.38	1.84	1.65	1.82	6.69
Hope	1.71	1.84	2.20	1.38	7.13
New Westminster.....	1.55	1.62	2.65	1.03	6.85

The above table shews an average in the irrigating district of 137, and in the non-irrigating district of 205 cubic feet per acre a day, or half as much again in the latter case as in the former.

The years 1877 and 1878 were, however, dry seasons in the non-irrigating, though fully up to the average rainfall in the irrigating district. The mean rainfall in New Westminster for 14 years was for the above months, 3, 18, 2.41, 2.42, and 1.67 respectively, equivalent to 288 cubic feet per acre a day. The rainfall in May, 1878, at Kamloops was 1.85 inches, equivalent to 216 cubic feet per acre a day, and it appeared to be the general opinion that with a similar rainfall during the season irrigation might, at all events to a very great extent, be dispensed with.

It must be remembered, however, that as art cannot compete with nature in the equable distribution of water, a larger quantity is required for artificial irrigation than would constitute an abundant rainfall. And it may further be observed that the rainfall which would constitute an ample supply for the generally retentive soils of the lower, would possibly prove inadequate for some of the soils of the upper country.

Further, in the irrigating district, a heavy precipitation is often the esult of sudden and violent storms, the effect of which is sometimes

more injurious than beneficial. An instance of this occurred on the 20th July, 1878, when a sudden storm burst on the Bonaparte Valley, with the result that several acres of cultivated land were covered with wash gravel, the crops destroyed, and that portion of the farm rendered worthless. It is obvious that such a storm would largely increase the registered rainfall, though its effects were simply disastrous. In the farming lands of the non-irrigating district, storms of this description are almost unknown, the rain falling more frequently and less violently, and with a corresponding increase of beneficial effect.

LOSSES OF WATER.

There are three principal heads under which the losses of water after leaving the reservoir or stream may be classified, namely :—

Loss by evaporation,

Loss by leakage in transit, and

Loss in distribution.

As regards the first there are no data derived from experiments in this province from which to deduce any conclusions. In California loss by evaporation does not appear to be taken into consideration.

On this point the following are the opinions of some eminent English engineers :—

Mr. Bateman places the loss by evaporation at from 9 to 16 inches, with an average of 12 inches.

Mr. Hemans allows from 12 to 14 inches.

Mr. Duncan estimates 11 or 12 inches as the constant loss at Liverpool, and found the loss varied little, even with considerable difference of rainfall.

Mr. Hawksley says : "Evaporation is more nearly 15 inches than any other quantity."

Careful experiments, extending over a period of 25 years, made in Hertfordshire, England, shewed that with a mean annual rainfall of 26.609 inches, the mean percolation was 8.227 inches, and the mean loss by evaporation 18.382 inches.

Mr. Dempsey quotes the following results of experiments made in Yorkshire during five consecutive years : mean annual rainfall 24.6, mean annual percolation 4.82, which gives double the loss by evaporation recorded in Hertfordshire.

Dr. Dalton gives the following results : mean annual rainfall 33.56 inches, mean evaporation 25.158, and mean percolation 8.402.

By another set of observations, quoted by Dempsey and also by

Haskoll we have: mean annual rainfall 26.614, mean percolation 11.294, mean evaporation 15.32 inches.

To tabulate them we have

	Rainfall.	Evaporation.	Percolation.
1st.....	26.609	18.382	8.227
2nd.....	24.6	19.78	4.82
3rd.....	33.56	25.158	8.402
4th.....	26.614	15.32	11.294

The mean of these various independent observations would give rainfall 27.846 inches, evaporation 19.66, percolation 8.186, or in round numbers the loss by evaporation would be about seven-tenths, leaving about three-tenths of the whole rainfall for percolation.

These results, however, are for the entire year; during the summer months the evaporation is probably much greater.

The amount lost in transit by leakage and evaporation has, in some cases, been estimated at 50 per cent. of the amount entering at the head of the ditch. It is obvious that the quantity lost through these causes depends upon the construction, the length and exposure of the ditch. The loss by filtration may often be reduced by the construction of timber flumes when the soil is porous, and by throwing into the ditch at intervals small quantities of soil, which being first carried along in suspension, and then gradually deposited, assist the consolidation of the bottom and banks.

The main conductors are often necessarily carried along steep side hills, and around bluffs and across ravines in timber flumes. These ditches and flumes have generally been set out and constructed by their owners, and as a rule most successfully, though in some instances too great a gradient having been adopted, overfalls have been found necessary at intervals to reduce the velocity which threatened serious damage. In one or two instances when the water refused to disobey the laws of gravity and flow up hill, heavy losses have been the result to the unfortunate projectors.

The loss in distribution may be reduced to a minimum by the proper preparation of the surface for the reception, and by making adequate provision for the distribution of the water. No hard and fast rules can be laid down by which to estimate these losses, each case must be treated on its individual merits.

QUANTITY OF WATER.

It has been customary in this province to record and claim one inch of water per acre, or 2536 cubic feet per acre a day. As to the amount

necessary, one cubic foot a second, or 34 inches, will cover four acres to a depth of over six inches in a day, which certainly appears to be a not unreasonably low estimate of the quantity required at each period of irrigation.

On this assumption, and that the land requires irrigating once in 25 days, 34 inches will irrigate one hundred acres of land, and 34 inches on 100 acres is equivalent to 864 cubic feet per acre a day. Judging from the quantities given by Mr. Burnell as required in Europe this amount should prove ample.

It is generally considered by engineers that from one-half to two-thirds of the whole quantity delivered is lost or wasted. Now the amount delivered at each period of irrigation on one four acre tract is 86,400 cubic feet, or 21,600 cubic feet per acre a day; deducting three-fourths of that amount for all losses, we have 5,400 cubic feet per acre at each period of irrigation, or a daily average throughout the irrigation season of 216 cubic feet per acre per day actually utilized, equivalent in round numbers to a monthly absorption of 1.8 inches of rain. As, however, it is doubtful if more than one-third of any rainfall is actually absorbed, this amount may fairly be taken as equivalent to from 5 to 6 inches of rainfall. With such a rainfall it is certain that irrigation would be unnecessary. If the superfluous water be utilized on lower lying lands, the result will be found to be an approximation to the Californian standard of one cubic foot a second for each one hundred and sixty acres under cultivation.

In the author's opinion 34 inches delivered upon the land will be found ample to irrigate from 100 to 150 acres of cereals or roots according to position and soil.

It is generally considered that grass requires a larger supply of water than grain, and in estimating that quantity we are again confronted by a total want of data in this province; but since it is known that rice needs 1440 cubic feet per acre a day, it would appear reasonable to assume an approximate mean, say 45 inches delivered on the ground, for each hundred acres of grass under cultivation.

In assuming these quantities it is thought that an ample margin has been left for all losses in distribution, and the author, though anxious not to under-estimate the quantity required, feels considerable doubt as to whether, with proper construction and handling, two-thirds of the amount would not prove sufficient.

To give an example of the enormous quantities supposed by some to be required: on a certain farm it was found that the main conductor close to the land to be irrigated had a velocity of 2.35 feet a second,

with an area of 1.25 square feet, equal to a daily discharge of 253,800 cubic feet or 100 inches. It was stated that the season lasted ninety days, that the irrigated area comprised about 50 acres of grass and 30 acres of grain, that during sixty days the grass received the water and during thirty days the grain. We have then the astounding result, that throughout the season the grass received an average of 3,384, and the grain 2,820 cubic feet per acre a day, equivalent to over 26 inches of rainfall a month, or enough in ninety days to convert the whole area into a lake over 6½ feet deep. Probably not more than one-tenth was of actual service, and when compared with other results, it will appear that in this case at least the supply exceeded the legitimate demand.

DRAINAGE.

In this province but little has been done, and in most cases, from the natural contour of the land and the character of the sub-soil, but little requires to be done for the purpose of removing the surplus irrigation water. When, however, it does not naturally and rapidly flow off, its drainage is as essential as its original introduction.

FALL OF MAIN CONDUCTORS.

It is apparent that the main conductors are frequently constructed with too heavy grades, and it is suggested that the velocity should not be greater than from 1 to 2 feet a second through earth, and 3 to 4 or 5 feet in timber flumes.

With regard to flow in open channels, Colonel Waring calls attention to a result he has observed in the flow of sewers in the following words :

"One principle is very apt to be disregarded in regulating the size of sewers ; that is, that after water has once fairly entered a smooth conduit, having a fall or inclination towards its outlet, the rapidity of the flow is constantly accelerated up to a certain point, and the faster the stream runs the smaller it becomes ; consequently, although the sewer may be quite full at its upper end, the increasing velocity soon reduces the size of the stream, and gives room for more water. It is found possible, in practice, to make constant additions to the volume of water flowing through a sewer by means of inlets entering at short intervals, and the aggregate area of the inlets is thus increased to very many times the area of the sewer itself."

The author has on two or three occasions observed results confirmatory to a certain extent of this statement, and would be glad to learn whether the point has attracted the attention of others, and how far it

is available in practice. Except by Colonel Waring, he has never seen the matter referred to in any works of reference to which he has access, and though probably of not much practical importance in the construction of such channels as drainage and irrigation ditches, he would submit that it may prove a serious point for consideration in designing such costly subterranean works as sewers.

From the drawings accompanying this paper Plate VII has been prepared.

CORRESPONDENCE.

Mr. M. J. Butler said that he believed the subject of irrigation to be one of the most important in this country, applicable not only to the regions of slight rainfall, but largely to the whole of Ontario and parts of Quebec. With irrigation and proper drainage, for the two should go together, a certain crop is insured year after year. Mr. Butler.

In Italy, where the rainfall is quite equal to our own, viz., about 39 inches, enormous sums of money have been spent in irrigation works.

"In France, Italy and most of India the rainfall is ample for ordinary crops, irrigation is adopted to prevent the failure of crops by droughts. These reasons apply equally as well to all other countries; the general impression that irrigation is only necessary and useful in dry countries is entirely incorrect." See valuable paper in Vol. XVI Transactions Am. Soc. C. E., by E. B. Dorsey.

It is to be regretted that the so-called Miners' inch as a measure of volume has been permitted in British Columbia. This measure has been aptly defined as a "nondescript inch which can scarcely be credited with a remote approximation to correct measurement," and it seems to vary in volume with the state or place where it is used. In Idaho it is "partly by custom, partly by statute, the quantity of water which will flow through an inch square orifice in an inch board, with a head or pressure of four inches above the centre of the orifice, but is in reality the quantity of water which will flow through an inch square orifice in an inch board, with a head or pressure depending upon the care used in adjusting the gate which admits the water to the orifice." In Colorado on one occasion he saw a description which read "The lessee is entitled to six inches of water," and he endeavored to find out how many cubic feet it was intended to cover, but could not do so until he hunted up the engineer who had prepared the lease.

The description of what constitutes an inch in British Columbia, or a multiple of one, does not specify the thickness of the plate, nor how made. When it is considered that the co-efficient for construction depends upon the kind and size of the orifice, it will be seen that a not very accurate measurement will be the result. An admirable, cheap and simple device has been designed by Mr. A. D. Foote,

M. Am. Soc. C. E., and is described in Vol. XVI, Paper No. 355, Transactions Am. Soc. C. E.

The subject of loss of water in conduits by evaporation is an important one, on which but little data are available in this country, and the writer knows of no authority so good as that of Mr. Desmond Fitzgerald, who has carried out an extensive series of experiments at Boston, and which are described in Transactions Am. Soc. C. E., Vol. XI.

Thursday, 24th April.

E. P. HANNAFORD, Vice-President, in the Chair.

Paper No. 42.

THE SAULT STE. MARIE BRIDGE.

By G. H. Massy, M. Can. Soc. C.E.

The completion of "The Sault Ste. Marie Bridge" adds one more to the number of great International bridges joining Canada with the United States, and forms the connecting link between the Canadian Pacific Railway and the network of roads traversing the Western States.

In the autumn of 1885 it was decided, by the Sault Ste. Marie Bridge Co., to build a bridge across the Ste. Marie River at "The Soo," and a party was organized to make the preliminary surveys, from the results of which it was decided to construct the bridge at the upper end of the Ste. Marie's Rapids, where the smooth water of the Lake commences to break away over the rocky bed of the river. The bottom is formed of smooth, level sandstone of the Potsdam formation, perfectly bare of gravel or *debris*, with the exception of Pier No. 1, where a considerable deposit was formed. In the winter of 1886-7 the contract for the construction was awarded to R. G. Reid, who the year before completed the St. Lawrence Bridge. Early in May the contractor and the engineering party arrived at "The Soo," and the work of triangulation commenced, and here it may not be out of place to go a little into the general detail of accurately determining the position of the piers.

The first operation was the measurement of a base line and the calculations of angles. The most scientific and practical method of setting out piers is by means of angles from a measured base, direct measurement by a long wire has been advocated by some engineers, but the experience of the author on this method has not been satisfactory. It may appear a very simple matter to measure 700 or 800 feet on a wire, and then transfer this distance between two points supported only at the ends, but the result of such is often unreliable, as was experienced by the engineers at the Forth Bridge. For distances of 400 or 500 feet, with great care, accurate results can be obtained, as the sequel will show.

In setting out by angles, the instruments used will first be discussed; these are three in number,—a transit, steel tape and picket. The transit should not be less than 8" diameter, reading to 10 seconds. The one used at the St. Lawrence Bridge and "The Soo" was of this description, made by Hammersly of London, being furnished with a very powerful glass and long sensitive level underneath the telescope. There was no vertical arc, but simply the ordinary clamp screw; on this instrument five seconds could be estimated. For distances over 3,000 feet the author would recommend a 12 inch instrument, such as that used at the Forth Bridge, or better a 16 inch reading to five seconds. The author also thinks it would be an advantage to have the upper plate moved by a wheel attached to it, working into teeth set near the outer rim of the lower plate, thus ensuring a relative motion between the plates, and avoiding the danger of moving the lower plate when the upper plate is moved round, as this is one of the most serious causes of error in taking angles. The glass should be such as to show an ordinary picket clearly at a distance of one mile, so that the hairs can be set on an object to one inch at that distance. Accuracy of graduation is also one of the essentials. The transit above mentioned weighed about 40 lbs., and when not used on a fixed pedestal, was attached to a heavy wrought iron tripod weighing 80 lbs.

The next instrument is the steel tape. At the suggestion of the author the company ordered from Chesterman, England, a tape of heavy steel 500 feet long, and the result shows the accuracy of the work done with it.

Thirdly, we come to the picket, or centre used. These were designed by the author for the "Soo Bridge." They were made of 2 inch gas pipe, about seven feet long; the lower end being screwed into a socket formed like a fork, the two prongs of which rested on the hub, the centre of the pipe being placed accurately over the nail by means of a plumb bob and line, the line being fastened to the centre of the upper end and the plumb bob swinging in the fork below, thus ensuring the centre to be both exactly vertical and on the nail. The picket was then secured by four wires fastened to the upper end and to stakes driven into the ground; these wires could be adjusted for length by swivel screws, such as are used to tighten the ordinary buck-saw frame. The pickets were painted white, and a black board placed at a little distance behind to make them more distinct.

Now, in selecting a base, it is preferable to have one on either side of the river; one half of the piers being laid out from one and their positions checked from the other; a most satisfactory check on the work being to calculate one base from the other.

Of course the more level the ground is the better, and if at all possible each end of the base should be visible from the other, but it often happens that level ground cannot be had. The base for the St. Lawrence Bridge was measured with an ordinary 100 foot steel tape, laid on strips of board supported by hubs driven in about ten feet apart, and the ends cut off to a level. Where the ground fell away a lower set of levels were taken, and the distance plumbed down at each break. This was done with great accuracy, considerable time being spent at it. By careful measurement the error should not exceed $\frac{1}{1,000,000}$. This base was measured before the author took charge of the St. Lawrence Bridge. The plan adopted at "The Soo" was to drive in stakes 1" × 2" ten feet apart, exactly in a straight line along the base from a point 25 feet above the centre line of the bridge to the point at which the transit was to be placed. A line was taken along the stakes, regardless of levels, from one point to the other, and large nails driven into the stakes to support the tape. At every 500 feet a firm staging was built, on which the exact 500 feet was marked, and the tape moved on to its next position, and so on till the base was measured. This was repeated three or four times, the tape being always stretched by a spring balance under a tension of 50 lbs. The 500 foot tape while under this tension was checked with a 100 foot standard tape, the latter having been previously compared with the standards used by the company who were to build the superstructure of the bridge. The temperature was also carefully noted, and the length of the base reduced to a normal temperature of 60° Fahr. and also corrected for slope. At the St. Lawrence Bridge a good base was obtained on both sides of the river, and the accuracy of the triangulation and measurements checked by calculating one base from the other, but at "The Soo" the two bases had to be measured on the south side. When the base was fixed, a solid oak post was placed at one end and a hub let into the rock at the other. The large transit was set on this post, and all the angles to the several piers laid off from it. An ordinary transit was set over the other, this point being, as was stated, 25 feet above the centre line of the bridge, and a corresponding centre set up on the opposite side of the river, also 25 ft. above the centre line of the bridge on which the cross hairs of the transit were set. All the piers were laid off from this upper line. The object of keeping this line 25 ft. above the bridge was to clear all derricks, scows, etc., at the same time admitting of a point being fixed on the upper end of the caissons.

The distance across the river at "The Soo" was about 3,000 feet. This being calculated from two entirely independent sets of data, the

results checked *to the tenth of an inch*, the whole of the work, including measurement of basis, taking of angles and calculations, did not occupy one week. This calculated distance agreed with the taped distance, after the construction of the bridge, to 1½ inches. The author may add that the calculated distance and the measured distance on the St. Lawrence Bridge agreed to 2½″ on a distance of 3,700 feet. The base used for setting out the piers at "The Soo" was about 1,900 feet long. A small shanty was built at either end to protect the instruments, and on the roof of these, exactly over the centres, two pickets were set, of the kind previously described. These were checked from time to time by means of the plumb bob. The instrumental work required much care and patience. All the angles had to be repeated several times to eliminate all eccentricity in the centering of the transit. It was found that the lower plate of the transit was liable to slip while moving the upper plate; thus after taking the three angles of a triangle, the sum was usually less than 180° by some seconds. To avoid this error the following method was adopted: Zero of the transit was first set on the far end of the base, and the upper plate moved till the hairs intersected the picket on the far side of the river. The angle was then noted, and the upper plate moved round in the same direction till the hairs intersected the first picket. Now, if the vernier did not read zero, it was evident the lower plate had shifted, and the operation had to be repeated. When this angle was satisfactorily recorded, the vernier was set at 10°, the hairs set on the first picket and the upper plate moved round to the second picket, the angle read, then moved round to 10° and checked to see if the hairs were on the first picket, and so on, increasing by 10° each time, when the average was taken. By this means great accuracy was attained, any small discrepancy of a second or two being distributed between the three angles in proportion to their size. In setting out the piers the same precautions were taken. In reading the verniers, a sheet of white paper was placed close to the plate, and the reading taken through a small hole cut in the paper. This paper threw a shade on the vernier, and the graduations could be seen with great distinctness. Close beside each of the shanties, a signal was erected, which could be worked by the man at the transit, without taking his eye from the instruments. As the caisson approached its proper position, a man on board held up a picket, which was immediately signalled into its exact position by the transitman, and by this means the men who guided the caisson were enabled to see which way it had to go without any confusion or mistake. When the caisson was placed by the transits, its position was verified with a steel wire of given

length, usually the length of a span. This wire was about $\frac{1}{8}''$ diameter, the exact length marked on it by a loop soldered on at each end; one loop of the wire was brought exactly over the starting point by means of a long adjustable screw arrangement, the other was carried in the boat to the caisson and strained to 200 lbs. and the exact distance marked. Very correct measurement can be made in this way, but it is necessary constantly to check the wire under strain with the standard tape, and also when not in use to roll it on a reel made specially so as to prevent the wire getting bent. At the St. Lawrence Bridge, the 408 ft. cantilever spans were measured in this way, and when the iron work was connected, the measurements agreed exactly on one of the 408 feet spans, and on the other there was a discrepancy of only $\frac{1}{4}$ inch.

In setting out piers from a base line, the question will arise as to the length of base which will give the most accurate results, assuming that the transit reading may be liable to an error of (a seconds) when (a) may be 1 to 5. It may be shewn mathematically that this length should be equal to the length from the base to the pier measured along the base, or that the angle below the base line and a line from the transit to the pier should equal that between this line and the bridge line. This would shew that theoretically the best results are obtained by having a separate point on the base for setting off each pier. The author believes that this was carried out at the International Bridge at Buffalo.

The next operation was to level across the river. This was done by placing three of the best levels on each side of the river, and reading on a large rod graduated to $\frac{1}{10}$ of a foot held up on the opposite shore; when the three readings were taken the rods were held up at as nearly as possible equal distances, but on the same shore. Thus the errors of curvature and refraction were neutralized by these equal sights. The error in levelling by this method should not exceed $\frac{5}{100}$ in 3,000 feet, when the levels were transferred across two stands for the large transit wire set up just above the bridge line, one on either side of the river, and opposite each a target placed, whose centre was exactly on the same level as the cross hairs of the transit when set on the opposite stand. Thus by setting up the instrument and directing its cross hairs on this target, a correct level was ensured The only source of error was in certain states of the weather, the refraction being so great as to cause an error of $\frac{1}{10}$ of a foot in the line of levels; but slight errors in levels, except in the case of continuous girders, are of little consequence, much less than errors of distance, as the appearance of a bridge not sitting fair on the centre of the piers has a very bad effect. During the time occupied in triangulation, the contractor was

employed building a temporary wharf for landing stone and other material and excavating foundations for abutments. Most of the plant used in the construction of the St. Lawrence Bridge was shipped to "The Soo," and comprised two tugs, 22 scows, three of which were furnished with steam derricks, two pumps, six large anchors, two clam shell dredges, and other but less important implements used on such work. The depth of the water on the site of the bridge varied from 2 to 12 feet.

Although the extreme rise of the river, except after a westerly gale, does not exceed $2\frac{1}{2}$ feet, it is at any time liable to $1\frac{1}{2}$ feet rise in less than an hour, due to some wave motion of the Great Lakes. The swiftest current is where the water is deepest towards the Canadian side, and attains a velocity of 9 miles per hour. The shallowness of the water rendering it impossible to bring the tugs within less than 300 feet of the piers, the scows and caissons had to be lowered down by ropes.

The plan of foundation is similar to the St. Lawrence Bridge, namely, caissons with water-tight sides of 12″ × 12″ timber, without any bottom, the sides scribed to fit the rock. The caissons were so designed as to allow a space of 4′ 6″ between the timber and the sides of the piers. A curtain of canvas was nailed round the inside of the caisson to check any current while depositing the concrete.

The concrete was formed of sand and Portland cement in equal quantity, to which was added as much broken stone as the mortar thus made would take. This concrete was deposited by the same boxes as were used at the St. Lawrence Bridge, and described in a paper by the author.* The depth of the concrete was never less than half the depth of the water with a minimum depth of two feet. The second day after the concrete was deposited the caisson was pumped dry, the bottom levelled, and masonry commenced. In building with timber caissons and concrete bottoms, the depth of the latter should not be less than $\frac{1}{3}$ the depth of the water with a minimum depth of two feet. Less concrete than this is apt to cause troublesome leaks, and the concrete box should hold two cubic yards. The masonry of the small bridge on the Canadian side was commenced June 9th; and the north abutment of the main bridge on June 2nd, but no masonry was laid in the river piers until August 9th; as much time was lost in negotiating with the United States Government as to duty on plant and material, etc. The last of the masonry of the Main Bridge was laid October 7th.

The work proceeded rapidly and smoothly without serious mishaps or accidents of any kind, the experience gained on the St. Lawrence Bridge

* Transactions Can. Soc. C. E. Vol. I., Part I., page 39.

by the men employed proving of great service. No. 1 Pier was the most tedious, as a large quantity of gravel had to be dredged off by means of a large rake attached to a long handle, operated from scows anchored over the foundation, any remaining gravel being cleared off after the caisson had been placed. The most troublesome and costly foundation was the centre pier of the Swing Bridge. This had to be carried down 22 feet below water level through seamy rock, in anticipation of the enlargement of the canal at some future date. The pier was circular, with a diameter of 30 feet, the excavation being several feet wider; leaving only about 20 feet of rock between the pier and the canal, through which the water poured like a river, requiring the constant use of two large rotary wrecking pumps until the masonry reached the water level. The stone used in the swing bridge and the bridge at Canal Street was Ohio sandstone, the remainder being white limestone from the Owen Sound Quarries. The general plan of piers and abutments are similar to those of the St. Lawrence Bridge, the piers of the Main Bridge all being 10 feet wide on top.

The following is a brief outline of the bridge: Commencing on the Canadian side, the approach to the bridge is a timber trestle 1500 feet in length, with two spans of iron crossing a small branch of the river, then 1900 feet more of trestle to the main bridge consisting of 10 spans of 242 feet each, pin connection through girders: then 350 feet of bank which reaches the north abutment of the swing bridge over the Ste. Marie canal. The swing has a total length of 396 feet, crossing the canal at an angle of about 60°, then another bank of 200 feet, and a plate girder over Canal Street reaches the southerly limit of the Bridge Co.'s property.

DISCUSSION.

Mr. Blackwell. Mr. K. W. Blackwell asked if the author had noticed any change in levels in Lake Superior to correspond with tidal movements. He had seen it stated that there was a slight movement twice in the 24 hours in the waters of the Great Lakes, occasioned by the same physical influences which caused tides.

Mr. Hannaford. Mr. E. P. Hannaford said the author had gone to a great deal of trouble to give the profession every information interesting and valuable in regard to laying out piers, leaving little for discussion.

Mr. Irwin. Mr. H. Irwin said the author had mentioned the advisability of constructing the transit with gearing attachments connecting the upper and lower plates, so as to avoid the movement of the lower plate when moving the upper, and wished to know if the author knew of the "reiterating transit," that is, a transit with only one spindle, the lower plate being a fixture. It was not quite so handy since the vernier could not be set to zero before pointing the telescope at the back sight, but it practically did away with the slipping. These transits are used by Dominion land surveyors in running the outlines of townships. He did not think a rack and pinion connection would work satisfactorily. He knew of a very expensive instrument with the rack and pinion movement, but it did not prevent slipping. In the North-West, reiterating transits were much used on account of their accuracy.

With regard to levelling across the river, he suggested setting up the instrument first on one side of the river, and reading a bench mark close by and also reading a bench mark on the other side of the river, and then going to the other side of the river and reading the same bench marks similarly. In this way there was a good check upon the curvature and refraction. He had tried this method across the Richelieu River, P. Q., but the distance there was not greater than 900 ft.

Mr. Goad. Mr. C. E. Goad said the author had apparently experienced the

same difficulty as he had on a bridge upon the Montreal & Ottawa Railway, where the river was about 700 feet across. A steel wire could not be depended upon for accuracy; and triangulation was resorted to.

Mr. H. Irwin remembered reading, that in building the Forth Bridge a steel wire was found to be satisfactory as a check measurement. It was strained by known weights, and the difference from the calculated length was small in the distance of about 1700 feet. Mr. Irwin.

Mr. E. P. Hannaford said that reference had been made by the author to the International Bridge at Buffalo. This bridge was built by the present president of the Society, the speaker being the engineer, and Mr. Joseph Hobson, M. Can. Soc. C. E., the resident engineer. On the Canadian side a base line was laid out at an angle of about 90 degrees with the line of the bridge, and its length checked by rods and a steel tape, then another or check base was established on the American side. The position of the piers was given by a fixed transit in the line of the bridge and another transit at the end of the base line. The Niagara River at the site of the bridge is very deep with a strong current and bad anchorage. Mr. Hannaford.

The working out of the position of the piers and placing them by triangulation was eminently successful. There was no error due to calculation, and what little there was in exactly centering the inner and outer caissons of each pier was owing to the trouble in getting the caissons in their right position, because although a liberal allowance was made for lee-way, the depth of water—45 feet—and the rapid current caused the caissons to sway, or surge, although every precaution by means of side and bottom anchorage was resorted to. (See book on International Bridge, 1873, by C. S. Gzowski.)

He could not conceive how anyone could rely on wire for distances; it seemed to him a most erratic and unreliable method. He had never seen concrete boxes used as large as those mentioned by the author, containing two cubic yards.

Mr. C. E. Goad said such boxes would be heavy, but he certainly thought they are a step in the right direction. Mr. Goad.

Mr. P. W. St. George understood these boxes were lowered into the water, so as to get as near the river bed as possible before depositing the concrete. Mr. St. George.

Mr. Massy. Mr. G. H. Massy explained that the concrete boxes were constructed with the bottoms above the lower edges and opening at the centre, so that when the box rested on the foundation, the bottom could be opened from above, allowing the concrete to slip out gradually.

He considered the larger the concrete box the better; but of course this necessitated strong derricks and large scows. The contractor had found it difficult to handle boxes containing two cubic yards, but it was undoubtedly better to deposit concrete in large quantities.

Mr. St. George. Mr. P. W. St. George asked if, after depositing concrete from the boxes, the author had an opportunity of seeing how the concrete was left on the bottom, and whether the cement and sand had separated from the stone?

Mr. Massy. Mr. Massy replied that when the caissons were pumped out, there was every opportunity of observing how the concrete lay on the bottom, and there was generally about three inches of loose stone which could be shovelled off before reaching the solid concrete. It was more than probable that the next box of concrete would mix with and consolidate this loose stone. As to the state of the concrete along the sides of the caisson, he had watched the construction of a concrete abutment built on dry land, and when the planks were removed the concrete presented a solid face on which the mark of the grain of the timber could be seen.

Mr. St. George. Mr. St. George remarked that the sides would not have the same opportunity as the bottoms from which the stones would be heaved up, as was the case in road-making.

Mr. Hannaford. Mr. Hannaford asked what were the proportions of the concrete?

Mr. Massy. Mr. Massy replied that the proportions were about one of cement, one of sand, and four of broken stone. The object in making the concrete so rich was to allow for any loss due to the cement washing away from the sand during the process of submersion. He thought for this class of work the concrete could best be prepared by gangs of men sufficient to keep one box employed constantly.

Mr. St. George. Mr. St. George referred to the Aberdeen harbour and docks, in the construction of which concrete consisting of ten of stone to one of sand and one of cement was used; and to the Manchester canal, the concrete used in the main wall of which was in the proportion of twelve to one,

except the face work, which was four to one. This showed that in England an apparently much weaker concrete was used than in this country, which he said was because there the cement could be obtained fresh. Here such high tensile strengths were not obtained.

Mr. Massy thought the reason stronger cements were not imported was because engineers as a rule did not specify such, and manufacturers would not exceed the specifications. Mr. Massy.

Mr. St. George thought Mr. Massy was in error, as he understood there was no special method of making cement in England for exportation. He has visited the English factories, and considered the difficulty was in the fact that cement was held by for a time and then shipped to this country, so that they got old instead of fresh cement. His observation was similiar with tile pipes, agents often sending an inferior article to this country to that used in England. Mr. St. George

Mr. Hannaford said he had always understood that there was little difference in the various brands of standard manufactures of English Portland cement. His experience with concrete was that he should hesitate to use any weaker than one in six—one of cement to six of sand and stone. He preferred one in five—weak concrete was dangerous. He generally specified for two of sand and two of broken stone to one of Portland cement. It was better to be on the safe side when letting the work, as when tendering contractors were ready to bid the same for strong as for weak concrete. Mr. Hannaford.

Mr. Irwin said that some of the barrels of cement imported were smaller than those used in the United States and England, where they were $3\frac{3}{4}$ or 4 cubic feet. He had once tested the capacity of barrels of English cement, and found the average to be only $2\frac{1}{2}$ cubic feet. Mr. Irwin.

Mr. St. George said barrels of English cement weighed 370 to 375 lbs., German 400, and American 240 lbs. The city of Montreal purchased cement per 100 lbs., not by the barrel, and every tenth barrel was weighed. There were cements in the market that had been rebarrelled here; some in fact were reground here, having being injured by the voyage. Mr. St. George.

Mr. Massy said in reply to remarks, that he had not answered that the general weight of English cement was seven barrels to a ton. Mr. Massy.

He had noted the rise and fall in Lake Superior, but could not discover any law governing it, as the movement at times was most erratic. A movement towards higher water would often occur twice in a few hours, and then not for days. He did not think the effect of a tide was noticeable.

With reference to the rack and pinion attachment to the transit, he had never used such an instrument as mentioned by Mr. Irwin.

With regard to levelling across a river, he had never tried the method mentioned. The simplest way that occurred to him was to take two equal sights, and then eliminate every kind of error due to curvature, refraction, etc. He had read an article on the Forth Bridge by one of the assistant engineers, in which it was stated that the errors made by measuring with a wire amounted to 6½ inches, which they did not appear to be able to account for.

With respect to measuring distances by wire, he thought the simplest method was to suspend the wire on land, measure the length, then suspend the wire under identically the same circumstances over the points to be measured afterwards, again testing the wire on land. He had found on several occasions, with these precautions, that the wire had undergone a change in length.

Mr. Fairman.

Mr. F. Fairman said he agreed with the remarks as to the unreliability of measurements made by wire. His experience as a manufacturer was that wire made out of crucible cast steel and of high tensile strength was the only wire that could be at all depended upon, and even then the difficulty of annealing such wire, so as to render it the same throughout, was such as to prevent its being absolutely reliable for measurements.

Thursday, 8th May.

F. R. F. BROWN, Member of Council, in the Chair.

Paper No. 43.

GENERATION, DISTRIBUTION AND MEASUREMENT OF ELECTRICITY FOR LIGHT AND POWER;

APPLIANCES THEREFOR, AND PARTICULARS OF CANADIAN INSTALLATIONS.

By A. J. Lawson, M. Can. Soc. C.E., A.I.E.E.

Introduction.

Although hardly fourteen years have elapsed since the first application of electric arc lighting on a commercial scale, and only about nine years since the practical introduction of incandescent electric lighting, yet the production of electric currents by mechanical means had long before that time been successfully solved by men to whom our indebtedness is too often ignored. They were not patentees but inventors, and the splendid results of their labours were often freely given for the public benefit without thought of personal advantage. First among these disinterested discoverers and benefactors was Michael Faraday, who in 1831 discovered the law of induction of currents and the principles of magneto electricity, and who published to the world his researches with the remark, "I have rather been desirous of discovering new facts and "new relations than of exalting those already obtained, being assured "that the latter would find their full development hereafter," a prophecy now most amply fulfilled.

Profiting by the knowledge obtained from Faraday's researches, Pixii of Paris constructed in 1832 the first appliance embodying the principle of magneto-electric induction, and for several years thereafter many inventors worked on the same subject, but it was not until 1860, just 30 years ago, that Dr. Antonio Paccinotti, of Florence, invented the first

generator of electricity, having an electro-magnetic field and an annular armature, — a machine which may be justly described as the prototype of all the dynamo-electric machines now known as Gramme armature dynamos. The exciting current, however, was not obtained from the machine itself, as is now the common practice in all continuous current generators, but was derived from a battery connected to the wires forming the field winding.

In 1866, the idea of a self-exciting dynamo suggested itself, almost simultaneously, to Mr. S. A. Varley of London, England, and to Dr. Werner Siemens of Berlin, Germany. Mr. Varley patented his machine towards the close of that year, and the publication of the patent took place in July, 1867. In January, 1867, Dr. Siemens described publicly for the first time the dynamo-electric machine which he had invented the previous year. Sir Chas. Wheatstone also invented, about that time, a machine which was self-exciting, and which he had had constructed in the workshops of Mr. Augustus Stroh of London.

In 1870, Mr. Z. T. Gramme, of Paris, invented the armature winding which bears his name, and the commutator and connections thereto— one of the most important improvements in the development of dynamo-electric machinery.

In 1876, Mr. C. F. Brush, of Cleveland, Ohio, invented his arc light dynamo with cast-iron field magnets and cast-iron armature, a type of machine of which the first constructed is still running in Baltimore, and which, while closely resembling the Paccinotti and Gramme machines, had its distinctive peculiarities. From this machine and the series arc lamp, invented by Mr. Brush, may be said to date the commercial development of arc lighting; and it is probably to the interest evoked by the success which attended Mr. Brush's inventions that the present success of electric lighting generally is due.

In 1879, Mr. T. A. Edison, who had been engaged for some months in experimental work, produced a lamp, which gave rise to great expectations and much speculation. His experiments did not indeed result at that time in a commercial article, but they were the foundation of his success the following year, when he abandoned the attempt to use filaments of platinum-iridium wire and resorted to carbon as the light-giving medium. But it was not until 1881, when he succeeded in obtaining a really durable incandescent lamp, that the application of electricity to domestic lighting became a possibility, and its adoption only a question of time.

Mr. J. W. Swan of England and Mr. W. E. Sawyer of New York,

who had been experimenting on the same lines for probably a much longer period than Edison, both invented, about the same time, lamps embodying the elements of the success which afterwards attended their endeavours; but whilst to the three distinguished inventors mentioned is due the credit of the production of really efficient commercial incandescent lamps, the fact that they were simply perfecting the ideas of other investigators, who had long previously experimented on the same lines, seems to have been generally forgotten.

On September 4th, 1882, the Edison station for the distribution of current to supply incandescent electric lights, located in Pearl Street, New York, the first permanent station of its kind, was put into operation.

In 1870, not a single horse-power, whether produced by steam or water, was used for electric lighting, or for the manufacture of electric lighting apparatus, yet now it is estimated that out of a total of five and a quarter millions horse-power developed by steam engines and water wheels on this continent, half a million horse-power, or nearly ten per cent., is used in the production of electric current for the distribution of light and transmission of power, and in the manufacture of electrical machinery and appliances.

At the beginning of 1886, there were in the United States and Canada 450 local electric lighting companies operating central stations. At the beginning of 1887, the number had increased to 750; and at the beginning of 1889 to nearly 1,200; while in January, 1890, there were 1185 different companies operating central stations in the United States, 147 in Canada and 25 in Central America and Mexico, besides 266 gas companies, etc., engaged in electric lighting, making a total of no fewer than 1623.

At the end of 1886, there were 1,000 incandescent and nearly the same number of arc isolated plants. The number of private plants now in the United States is 3,925; in Canada and miscellaneous 196, and in Central America and Mexico 200; making a total of 4,300 isolated electric lighting plants, large and small.

The following was the condition of the arc lighting business at the beginning of the years mentioned:

Year.	Arc lamps in use.	Year.	Arc lamps in use.
1882	6,000	1886	96,000
1883	12,000	1887	115,000
1884	24,000	1888	150,000
1885	48,000	1889	210,000

while in 1890 the lamps in use number 235,000. Of these about

68,000 are of the Thomson-Houston manufacture, and 49,000 have been made by the Brush Electric Company.

Between November, 1886, and January, 1889, the number of incandescent lights in America more than quadrupled, increasing from 525,000 to 2,500,000. At the present time, there are fully 2,800,000 incandescent lamps in use, of which 808,500 are supplied from alternating current plants, and of these 408,350 with the necessary apparatus, including 25,000 converters, have been furnished by the Westinghouse Electric Co., 208,760 by the Thomson-Houston Co., 111,500 by the Fort Wayne Electric Co. and the majority of the remainder by the Brush Electric Co. since September last. In addition to these the Thomson-Houston Company has furnished plant for direct current distribution of a total capacity of 144,000 lamps, the Brush Company for nearly 200,000 lamps, and the Westinghouse Company for 45,000 lamps. The estimated total capitalization of electric lighting and electric manufacturing companies in America at the present time is $250,000,000.

ELECTRIC LIGHTING IN CANADA.

Being one of the pioneers in construction of electric lighting plant in Canada, and the manufacturer or constructor of nearly 30 per cent. of the total capacity of incandescence lighting installations now in operation in the Dominion, the writer submits the following brief history of the progress of the electrical industry in this country.

Ten years ago there was not one electric light plant in operation in Canada. The first plants erected were Brush arc plants of small capacity. About the end of December, 1882, some Thomson-Houston arc lights were placed on exhibition in Montreal by the Thomson-Houston Electric Co. of Canada (afterwards merged into the Royal Electric Co. of Montreal), lighting St. James Street, Beaver Hall Hill, and part of Dorchester street, but the first permanent installation for street lighting in the city was that supplied from a Brush dynamo owned by the Harbour Commissioners, who by this means lighted the harbour, wharves and approaches.

In the Fall of 1883, some 50 arc lights of the Hochhausen and Vandepoele systems were placed in the streets of Toronto, and Winnipeg also had some arc lights put into operation about the same time. In May, 1885, Ottawa adopted the Thomson-Houston arc light for its streets, replacing thereby both gas and oil, and in 1887 Quebec followed its example, and Halifax and other places followed.

In 1889, Montreal gave a contract for the electric lighting of the whole of its streets to the Royal Electric Co. for a period

of five years, a portion of the city having been lighted by the same company since 1886. Hamilton also is now lighted by the arc light, and St. John, N.B., has recently contracted for the lighting of the whole city, dividing the work between the companies operating the Thomson-Houston and the Brush systems, so that the following cities may be said to have adopted exclusively the arc light in place of gas or oil :—Montreal, Ottawa, Quebec, Hamilton, London, Winnipeg, Victoria, Vancouver, Halifax, St. John, N.B., St. John's, N.F., Moncton and Sherbrooke, besides the majority of the towns throughout the Dominion, so that comparatively little work remains to be done in arc lighting; incandescent lighting for residences and stores being the principal field remaining unoccupied, and there can be no question that the large majority of this work will be done on the alternating current system, which is so admirably fitted for the lighting of our widely-built cities and towns, and for the utilization of our numerous water powers for this purpose.

In 1882, two private installations of incandescent lights were made in the city of Montreal. The system employed was the Maxim, which was put into the St. Lawrence Hall and the Bank of Montreal. So crude was the construction of these plants that they proved unsatisfactory, and after a very short time both were discontinued. In the St. Lawrence Hall only one lead was carried from the dynamos to the lamps, the return being made through gas and water pipes, a method which, it need hardly be pointed out, would not now be permitted by the Board of Fire Underwriters. The wire used in the Bank of Montreal for mains did not even have the coating of paint which would have gained for it the misnomer of "Underwriters wire," but was merely single cotton-wound magnet wire. This is not pointed out as reflecting in any way on the Maxim Co. : all companies' systems at that time were about equally crude.

In the Fall of 1882, a contract was made for lighting the Canada Cotton Co.'s mill at Cornwall with the Edison light. A plant of 500 16 c. p. lamps capacity, constructed under the superintendence of Mr. Byllesby, now Vice-President of the Westinghouse Co., was started on the 28th day of February, 1883. In June, 1883, an exhibition Edison incandescence plant was placed in the "Mail" building, Toronto, but was discontinued a few months later.

The Montreal Cotton Co.'s mills at Valleyfield were next lighted in September 1883, 800 lights being placed: which number was subsequently increased to about 1100. The Canada Cotton Co.'s plant was also increased at the end of the year to 1200 lights, and it is now the largest private installation in Canada. In January of 1884, two compe-

titive plants of small capacity were placed in the Parliament Buildings at Ottawa, for the lighting of which the writer furnished, in 1886, Edison machinery of a total capacity of 1000 lights.

The first incandescence electric light station in Canada was started at Victoria, B.C., in January, 1887, and was followed by that at Vancouver, B.C., completed in September of the same year. The distribution from both stations is on the three-wire system.

The station at Calgary, N.W.T., was completed and started in October, 1887, and in January, 1888, the station at Valleyfield, with overhead conductors—at that time the best constructed of all the Edison stations in Canada—was put into operation. For these four stations the writer supplied and erected all the machinery, and remodelled the stations originally constructed in the two first-named places.

The Cornwall station on the Westinghouse A. C. system, completed the same year, was the first A. C. station in Canada.

Toronto is the only place in which underground wires have yet been placed, but the Edison station, from which they are fed, has only lately been put into operation. It is the intention of the older Toronto Electric Light Co. to put under ground the wires for arc lights and for the alternating current plant about to be installed.

The Barrie central station, which the writer has constructed, is the latest completed central station plant, and the only one in the Dominion on the A. C. system carrying 2000 volts in the primary wires and nearly 100 volts in the secondaries, and it is one in which the highest quality of insulation, both of primary mains and house wiring, has been used.

At the present time there are 13,530 arc lights and about 70,765 incandescent lamps in use throughout the Dominion. There is hardly a village in Ontario, having a population of over three thousand inhabitants, which has not an electric light station of some kind in operation, and few of the important towns of the other Provinces are without electric lighting. Most of these, it is true, are arc lighting stations, but about a dozen supply the incandescent light only, chiefly to stores and public buildings, the lighting of residences being yet scarcely entered upon. Several of the local companies which have hitherto supplied the arc light alone, or with a few incandescent lamps in series with their arcs, or in series multiple with them, have recently purchased and put into operation incandescence A. C. plants; and the various lighting companies formed for the supply of incandescent lights only, have also found it necessary in most cases to add arc lighting to their business, it having been sufficiently demonstrated that the incandescent light is unsuitable

for street lighting, the public demanding from electric lighting, whether arc or incandescent, a much better illumination than is usually obtained from gas lighting, and in this respect the incandescent light has failed to meet the expectations of its advocates. The Edison municipal system was used for street lighting on the Lachine Canal, and at Vancouver, B. C., Valleyfield, Que., and Chatham, N. B., but has been replaced by arc lights in the two first-named places.

The principal electric lighting stations in Canada of which the capacity is 100 arc lamps of 2,000 nominal candle power or over, or 1,000 incandescent lamps of 16 candle power or more, are :—

Place.	No. of Arc Lights.	Inc. Lights 16 c. p.	System.
Barrie, Ont.....	75	1,200	Ball Arc, Brush A. C. Incandescence.
Brockville, Ont.....	105	1,000	Ball and Reliance Arc, Slattery A. C. Incandescence.
Cornwall, Ont.....		1,300	Westinghouse A. C.
Gazette Printing Co., Montreal, Que....		1,350	Edison.
Halifax, N.S.....	200	1,950	Thomson-Houston and Fuller-Wood Arc, Slattery Incandescence.
"	250	1,400	Thomson-Houston and Ball Arc and Westinghouse A.C. Incandescence
Hamilton, Ont.....	394	2,000	Thomson-Houston Arc, Westinghouse A. C. Incandescence.
Joliette, Que.....	30	1,500	Thomson-Houston Arc and A. C. Incandescence.
London, Ont.....	100		Thomson-Houston.
"	150		Ball.
Montreal, Que.....	1,440	2,000	Thomson-Houston.
Ottawa, Ont.....	522		Thomson-Houston.
"		4,000	Westinghouse A. C. and Weston multiple-series.
Peterboro, Ont.....	137		Thomson-Houston.
Quebec, Que.....	692	1,000	Thomson-Houston.
St. Catharines, Ont..	105	215	Thomson-Houston Arc, Weston multiple-series Incandescence.
Sherbrooke, Que....	167	500	Ball and Thomson-Houston Arc, and T.-H., A. C. Incandescence.
St. John, N.B.....	325	1,000	Thomson-Houston.
"	205		Brush.
Toronto, Ont.....	750	1,000	Hochhausen-Wright Arc, and T.-H. series Incandescence.
* "		10,000	Edison.
Truro, N.S.....	60	1,800	Thomson-Houston Arc, Mather Inc.
Valleyfield, Que....		1,200	Edison.
Vancouver, B.C....	100	1,150	Thomson-Houston Arc, Edison Inc.
Victoria, B.C.....	50	1,200	Ball Arc, Edison Incandescence.
Winnipeg, Man.....	200	1,000	Brush and Thomson-Houston Arc, and T.-H. Incandescence.
* "		3,000	Edison.
Yarmouth, N.S.....	100		Fuller Wood.

* The two stations marked thus have the nominal capacity given here, but actually run at present about 20 per cent. of the number of lights at which they are rated.

The private installations for incandescence lighting in Canada, having a dynamo capacity exceeding 600 lamps of 16 c. p., are:—

Name of Owner.	No. of lamps 16 c. p.	System.
Canada Cotton Co., Cornwall, Ont.....	1,250	Edison.
Montreal Cotton Co., Valleyfield, Que.....	1,000	"
New York Life Ins. Co., Montreal, Que....	1,000	Brush.
Parliament Buildings, Ottawa, Ont.....	1,000	Edison.
Stormont Cotton Co., Cornwall, Ont.....	850	"
Gibson Cotton Co., Marysville, N.B.....	850	"
Canadian Pacific Railway Station, Montreal.	800	Thomson-Houston.
Magog Print Co., Magog, Que.....	700	Edison & Thomson-Houston.
W. Bell & Co., Guelph, Ont.....	600	Brush.

The following is a summary of the number of lights of the various systems now in operation in the Dominion:—

System.	Arc Lights.	Incandescent Lights.
Thomson-Houston.....	6,105	14,600
Edison.....	.....	23,500
Ball.....	3,529	1,660
Brush.....	615	3,300
Hochhausen (Wright's improved).....	750	.....
Reliance.....	1,780	.....
Westinghouse.....	.....	6,850
Slattery.....	.....	5,850
Craig.....	.....	4,515
Mather.....	.....	3,125
Weston.....	180	5,365
Fuller Wood.....	425	.....
Other systems.....	150	1,500

ENGINES.

Whether the system to be employed be the low tension incandescence, the alternating current incandescence, or the high tension continuous current arc system, the three which are to-day practically the only ones operated to any extent in America, one of the chief points to be considered in the construction of a station is the economical generation and application of the prime power. Unfortunately in a great many cases where steam power is used, it was assumed in the early stages of electric station construction that any kind of steam plant would answer. Old slide-valve engines, which drove machinery as antiquated as themselves in machine shops, saw mills, woollen factories, and like places during the day were used at night for the running of electric light

machinery, and very good reason naturally existed for the complaints made of the unsteadiness and unsatisfactory character of the lights supplied.

High-speed engines belted direct to the dynamos were next tried, and having been found to give much better results in point of steadiness, a number of builders, who had had no experience in such work, undertook the manufacture of this class of engines, and evidently tried to combine the old designs for agricultural engines, upon which their previous practice was based, with some of the principles embodied in the best class of engines sold in the United States for electric light purposes. The product was a mechanical curiosity, and a failure. It is safe to say that in not one of the Canadian shops building these engines in the early history of electric lighting in Canada was there a proper equipment for the manufacture of high-speed machines of any kind. No parts were made to gauge so that in the event of a break-down the broken part could be duplicated without sending it back to the shop as a model. A reaction soon afterwards set in in favour of slow-speed engines, especially for arc lighting, and at the present time, with few exceptions, engines of the Brown and Wheelock types are used in all arc light stations in Canada operated by steam power. For the running of incandescence plants, however, high-speed engines, mostly of American manufacture, have obtained the preference to which their excellent qualities and performance entitle them.

Brown engines furnish the motive power for the Central Stations in Montreal, Toronto and Winnipeg, both Brown and Wheelock engines are used in Halifax and London, and Wheelock engines in Hamilton, while Armington and Sims engines are the prime motors in the stations in St. Johns, N.F., St. John, N.B., Calgary, Alta., Vancouver and Victoria, B.C., and in the Parliament Buildings at Ottawa.

14,750 H. P. generated by steam engines is used for electric lighting and electric railway working in Canada.

The economy of many stations could be increased by the intelligent use of the indicator, instead of trusting to the valves of engines being properly set by guess work, as is now so frequently the case.

BOILERS.

With the exception of the Royal Electric Co.'s east end station in Montreal, the ordinary horizontal fire-tubular steam boiler has been used in every station. In that case the Babcock and Wilcox water-tubular boiler is employed. In some cases the Jarvis setting has been adopted, but not to any considerable extent.

WATER POWERS.

At Quebec, power is obtained at the Falls of Montmorency, nine miles distant, to drive the Thomson-Houston arc dynamos and Thomson-Houston A. C. incandescence machines.

At Peterboro, water power is used to drive Thomson-Houston arc dynamos, from which 137 arc lights and a number of Bernstein incandescent lamps in series are supplied. At Barrie, Ont., a stream five miles distant from the town furnishes the power for both the arc and Brush A. C. incandescence plants.

Also in Ottawa, Cornwall, Smith's Falls, St. Catharines, Welland, Dunville, Thorold, Sault Ste. Marie, Sherbrooke, Joliette, Valleyfield, Almonte, and some other places, for both factory and central station lighting, water furnishes the motive power, the total H. P. from turbines used for electric lighting and power transmission in the Dominion being 4520, or more than one fifth of the whole power utilized for this purpose.

ATTACHMENT OF DYNAMOS.

The dynamos are not coupled direct to engines in any of the Canadian stations. Ordinary double leather belting, made without seams or rivets, is generally used. In a few cases link leather belting has been tried, but the results have so far justified the opinion that this belting has been invented chiefly to find a market for scrap leather. Belting should not be overtaxed. One inch width of double leather belting running at a speed of 750 feet per minute will easily transmit one horse power, and at this tension will last a long time. Some dynamo manufacturers, in order to impose the belief that their machines use but little power, are in the habit of providing a much smaller margin than this per horse power. The only advantage, of which the contractor receives nearly the whole benefit, is that the first cost is decreased. The disadvantages, which affect the purchaser, are the necessary excessive tightness of the belt, and the consequent heating of journals, rapid wear of the belt, and large oil consumption. Rope driving may eventually be used as it has many advantages, but so far, with one exception in an isolated plant, the method has hitherto not been tried in Canada.

ARC LIGHTING SYSTEMS.

The arc lighting systems in use in Canada are the Thomson-Houston, Ball, Brush, Reliance, American or Fuller Wood, Hochhausen (Wright's improved) and Weston. The large majority of machines and lamps is of the Thomson-Houston and Ball systems.

In the Thomson-Houston, in the Brush and in the Fuller Wood or American systems a current of 9.6 amperes is used, with a pressure varying according to the number of lamps in circuit. In the Ball system a current of 8 to 8½ amperes has been the standard, but lately that company have supplied several plants having a current of only four amperes, the lamps for which are nominally of 1,000 candle power each. In the Hochhausen-Wright system, a current of 10 amperes is used. In the Weston system the current is about 18 amperes, and the P. D. between the terminals of each lamp 25 volts. On account of the short arc and the consequent hissing the Weston lamp has not found general favour in this country. The regulation of the Thomson-Houston machine is excellent. The lamp also has the merits of simplicity of construction and steadiness in running. The feed is purely gravitational like the Brush feed, controlled by electro-magnetic action, there being no clock-work or gearing. It is not, however, quite so steady as some clock-work arc lamps, and requires the feed rod to be kept very clean in order to secure the proper working of the clutch. With the rack and pinion lamps this point is not of such importance, and the difference in the running of the two kinds of lamps sometimes observed may, to some extent, be due to the cleaning of the clutch lamp rod having been neglected.

In regard to the rating of arc lamps some change seems to be desirable. At present lamps taking 48 volts and 9.6 amperes, lamps of the same voltage taking 10 amperes, and lamps of 50 volts and 8 amperes, are all compared the one with the other, and each is called 2,000 candle power, which is manifestly absurd. The current and pressure, or watts per lamp, should be given in all specifications, tenders and contracts.

STREET WIRING FOR ARC LIGHTS.

In wiring for arc plants, as is generally known, one wire of uniform section is carried from the machine to the lamps, where it is cut, one end being placed in the first binding post and the other in the second binding post, and so continued, the pressure falling on an average about 48 volts for each lamp in circuit, where the lamps, as is the general practice on this continent, are always run in series.

For lamps of 2,000 nominal candle power No. 6 and for lamps of 1,200 nominal candle power No. 8 wire American gauge, is used for the leads. Up to within the past two years, the insulation known as "Underwriters wire" was used, but lately this has given place to much superior quality. Unfortunately, there is still room for improvement even on the best which has yet been supplied in Canada.

SYSTEMS OF DISTRIBUTION FOR INCANDESCENCE LIGHTING.

In the distribution of current for incandescence lighting from central stations the multiple arc two-wire system with low tension continuous currents was first used during 1882 and 1883.

In private installations at that time the tree system of wiring was usually followed, and it has not yet been entirely abandoned, although used in very few installations at the present date. In one station in the Maritime Provinces wired on this principle, the pressure varies from 125 volts at the lamps nearest the dynamo to 110 volts at the furthest point of distribution. But since 1884, very few stations indeed and few isolated plants of more than moderate size have been constructed on other than the feeder system.

A very short experience of distribution on the multiple-arc system proved that lights singly controlled could not be furnished economically by it at a greater distance from the central station than a quarter of a mile radius. The three-wire system, invented by Dr. John Hopkinson, and elaborated by Mr. Edison, was a temporary and partially successful solution of the difficulty, but this system, although it greatly reduced the quantity of copper necessary, only increased the radius of distribution on a paying basis by another quarter of a mile, and, while satisfactory for thickly populated towns, still left the distribution of light in suburban districts or openly built country towns as far from attainment as ever. The adoption of the alternating current system of distribution solved the difficulty.

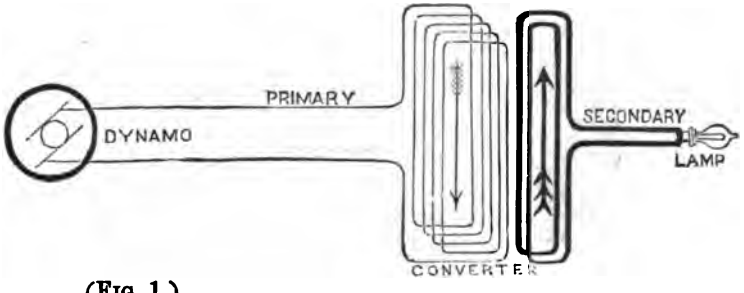
The method of regulation first employed for the maintenance of equal pressure at the ends of the feeders in the three-wire system consisted of placing adjustable resistances or feeder equalizers in each circuit, more or less resistance being inserted by hand, according to the indications of the pressure indicators. Where the frames of such equalizers were made absolutely fireproof, such a system of regulations in small stations having only three or four sets of feeders radiating from it was in a measure unobjectionable, but when it came to the distribution of several hundreds, perhaps thousands, of amperes of current, through dozens of sets of feeders, the loss in these equalizers became a serious matter, and perfect regulation was difficult of attainment. In several cases also the heating of the equalizers was the origin of fires which resulted in the burning down of the stations, the destruction of the Edison stations in Boston and New York being cases in point. In recent practice these equalizers have not been used, but a method of interlacing the feeders as well as the distributing mains has been adopted, necessitating a somewhat larger outlay in conductors, but not involving, as in the other case,

a loss of energy by the heating of useless resistance. With this interlacing the pressure at the lamps is much more nearly constant than under the old method.

At the price of labour and fuel and the selling prices current in this country, it may safely be said that the economical distribution of light or power, on the three-wire system, is limited to half a mile radius from the station in our most thickly populated towns. In both the United States and Canada, distribution by this system has been carried out on a much wider area for a limited number of lights and under special circumstances; but it is doubtful if there is a single city in Canada which will return any dividend on the necessary investment to a company placing low tension wires carrying a pressure of even 300 volts underground, and there are not more than six cities in the whole Dominion which will yield any return on this system with overhead wires, unless the charges for electric lights be at least 50 per cent. more than the current prices for gas.

ALTERNATING CURRENT DISTRIBUTION.

In the method of distribution by high tension alternating currents, the converters, indicated by Fig. 1, are placed in parallel circuit. As shown,



(FIG. 1.)

the high tension current from the dynamo does not enter the premises of the consumer but merely passes through the fine wire in alternately opposite directions, and generates, by induction, a low tension current in the secondary or thick wire of the converter or transformer, which induced current is carried into the houses and through the lamps.

There are at present no alternating current motors in use developing large powers, but probably before many months have elapsed machines will be supplied which will convert the electrical energy of alternating current into power with high efficiency. Ganz & Co., of Buda Pesth, have indeed

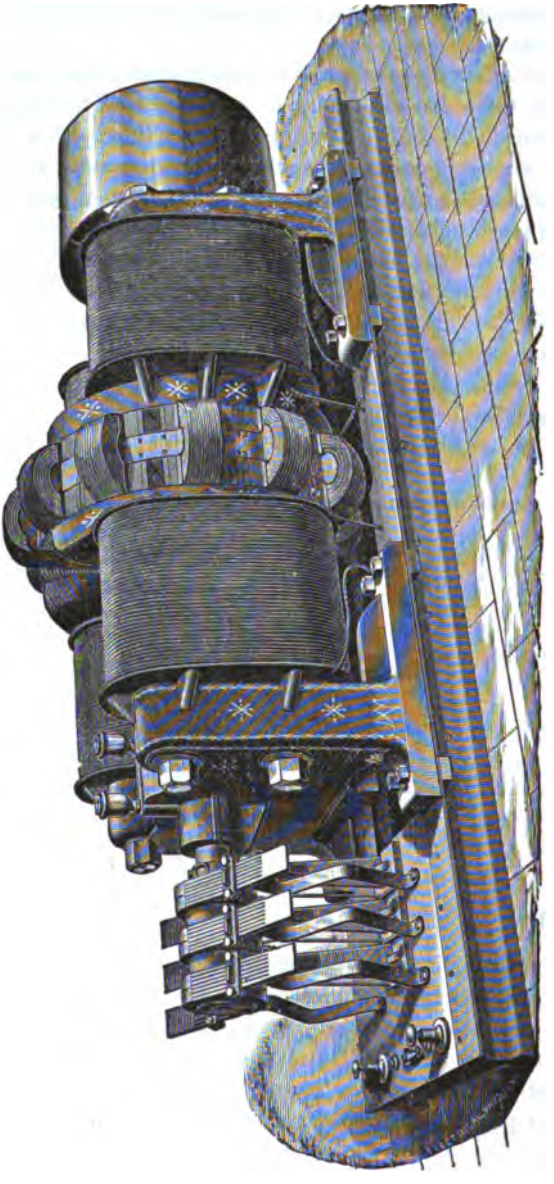


Fig. 2.

BRUSH ARC DYNAMO.

nearly completed a station from which to distribute power by A. C. motors, and the Westinghouse Company are just completing a contract for A. C. motors for mine working. It is also the case that the A. C. system will not easily lend itself to the charging of storage batteries, without a complication of commutators and other apparatus; but there does not appear to be any demand for the charging of storage batteries except what can be supplied from continuous current stations or isolated plants now n operation, or for which special dynamos would not be best use separate and distinct from any other circuit.

ARC LIGHTING DYNAMOS.

Brush Arc Lighting Dynamo (*Fig.* 2).

This machine was first made with both armature and field cores of cast iron; but for some years past the armature has been built up of laminated hoop iron of good quality, a simple modification which has raised the efficiency greatly, enabling the output to be increased 50 per cent. while running at the same speed as formerly. Upon the ring so formed the copper coils are wound. The 18-light machine weighs 1500 lbs., the 30-light machine 2500 lbs., and the 65-light machine 4800 lbs. complete. The P. D. at lamp terminals is the same as in the Thomson-Houston system, 48 volts, and the current is 9.6 amperes. The output of the first two sizes is 5.53 watts per lb. gross weight, and is 6.2 watts per lb. gross weight for the large machine. The respective speeds at full load are 1050, 950 and 805 revolutions per minute. In the 65 light machine the copper wire on the armature weighs 1340 lbs. and on the fields 1264 lbs., so that the output is 11.5 watts per lb. of the total weight of copper wire on the machine, and 22.35 watts per lb. of the copper wire on the armature.

Thomson-Houston Arc Dynamo (*Fig.* 3).

In the Thomson-Houston dynamo the field is composed of two massive iron castings upon which the magnetising coils of copper wire are wound, and these castings are of such shape that they nearly completely encircle the armature, being fastened together over it by wrought-iron bolts, which form the yoke or keeper. The armature core is a spheroid built up of soft iron wire. Upon this core three coils of copper wire are wound, these being connected together at their inner ends, their outer ends being carried out and fastened to a three segment commutator. The regulation of the current, which in all arc lighting machines should be maintained constant, is performed by an electro magnet which shifts the position of the brushes on the commutator, as fully described

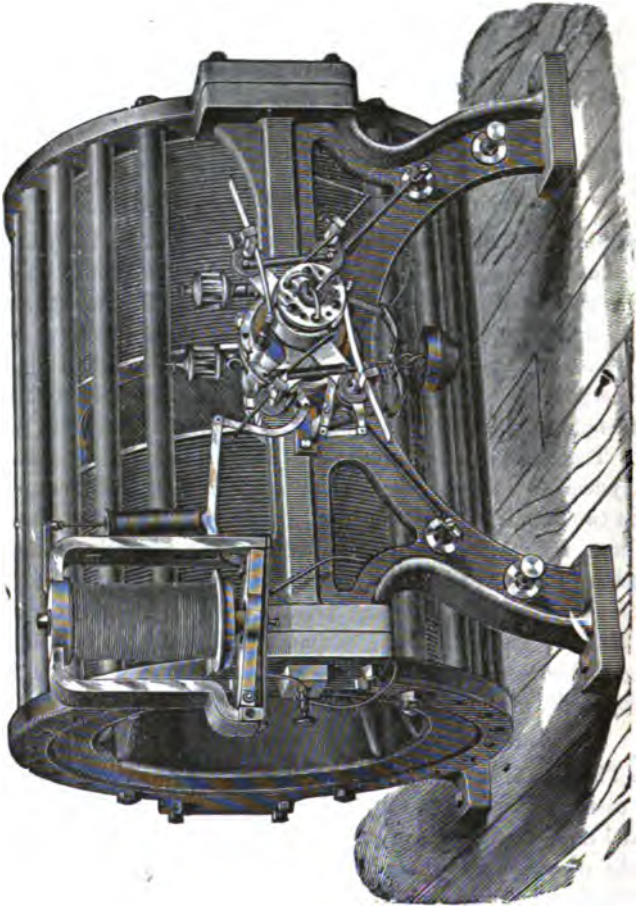
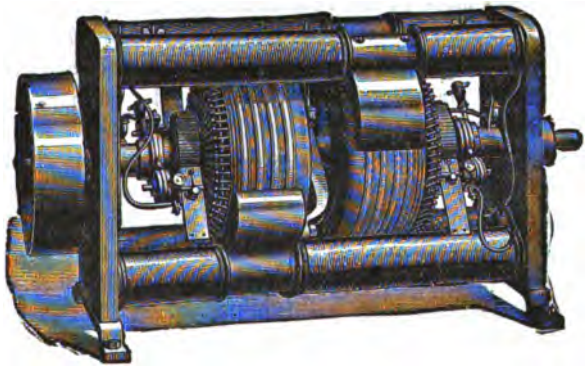


Fig. 3
THOMSON-HOUSTON ARC DYNAMO.

in Silvanus Thompson's "Dynamo Electric Machinery." The magnetism of this machine leaks outwardly to a considerable degree, which, of course, is a bad fault. There is also the objection to the form, that it is necessary, in case of breakdown of the armature, to dismantle the whole of the machine before the armature can be removed, and that that being done, should a coil be burned out it is necessary to completely rewind the armature—in itself the work of several weeks.

The nominal 50-light Thomson-Houston machine will run 60 arc lamps of 2000 nominal candle power on a short circuit of wire; and speeded at 850 revolutions per minute, has a working E. M. F. of 2700 volts with a current of 9.6. amperes. Its total weight is 6200 lbs. The iron in the armature weighs 340 lbs., and the two cast-iron field cores weigh 2710 lbs. The weight of copper wire on the armature is 378 lbs. and on the fields 820 lbs. The output is 4.18 watts per lb. of gross weight; 21.6 watts per lb. of copper wire on the machine; and 76.25 watts per lb. of armature wire.



Ball Arc Dynamo (*Fig.* 4).

The Ball arc light dynamo has a Gramme ring armature, or rather two armatures, running between blocks peculiarly placed one above one armature and the other under the other armature, and it has wrought-iron fields and pole pieces: in fact the whole machine frame is made of wrought-iron. It weighs much less therefore than other machines in which cast-iron is used, the 25-light machine weighing 990 lbs while the 35-light machine weighs 1180 lbs. complete. The current is $8\frac{1}{2}$ amperes, and the voltage per lamp 48. The output is 10.3 watts per lb. gross weight of the first machine and 11.97 watts per lb. of the 35-light machine. The weight of copper wire on the armatures

of the 35-light dynamo (there being two in each machine) is 102 lbs., and on the fields 150 lbs. The output is thus 56.6 watts per lb. of copper on the machine and 140 watts per lb. of copper wire on the armature. The speed of the two machines mentioned is 1365 and 1275 revolutions per minute respectively. The resistance of the field winding of the 35-light machine is 13 ohms, and of the winding of the two armatures 15 ohms.

The Ball Co. have recently made a machine intended for 80 arc lamps, of which the following are some of the particulars: Weight of the machine complete 3200 lbs.; current 10 amperes; E. M. F. 3750 volts; speed 940 revolutions per minute; wire on field 362 lbs. No. 10; on armatures 222 lbs. No. 15 B. & S. gauge; iron in each armature core 137½ lbs. The output of this machine is 11.66 watts per lb. gross weight: 63.21 watts per lb. of copper wire on the machine, and 168.83 watts per lb. of copper wire on the armature.

Toronto Arc Dynamo.

The machines made by the Toronto Electric Light Company for use in their own station are of the Hochhausen type, modified and improved by Mr. J. J. Wright, the company's electrician and manager. The company do not manufacture machines for sale, but make all their own arc light dynamos. Their standard type is a 40-light machine 10 ampere current, average P.D. at binding posts of lamps 48 volts. The field is laid horizontally, being, it may be said, a Hochhausen machine laid on its side. The field cores are of wrought-iron, the frame and pole pieces of cast-iron. The cast-iron weighs 1200 lbs. in each machine. The field winding consists of 700 lbs. of No. 9 copper wire, and on the armature there are 180 lbs. of wire. The armatures are sectional, the coils being wound separately on moulds. Each armature has 18 coils with Gramme connections. The commutator consists of 18 segments, and is mounted on slate with an air space between the sections. The weight of the completed machine being 2400 lbs., the output is at the rate of 8 watts per lb. gross weight; 21.8 watts per lb. of wire on the dynamo, and 106.6 watts per lb. of the copper wire on the armature. Mr. Wright in a communication on the subject sarcastically states: "Unlike all other systems our armature "coils sometimes burn out, and I have adopted the sectional style to "facilitate repairs. The power required I have not accurately deter- "mined, but it is nearly ¾ horse power per light—rather over than "under—when working to full current and voltage. I adopt a few coils "on armature rather than many, for while the spark at brushes is "larger, the increased simplicity of all parts more than compensates."

Westinghouse A. C. Arc Dynamo.

This dynamo, recently put upon the market, embodies several novel features. The frame of the 60-light arc machine is cast off the same patterns as the ordinary 750-light Westinghouse incandescence dynamo; and the only difference in the field windings is that the iron cores project through the coils to a greater extent than in the incandescent machine, the coils being shorter. The principal feature of the machine is the armature winding, which is almost entirely enveloped by the laminated iron discs forming the core, and is connected to two collecting collars as in the Westinghouse incandescence machines. The speed is 600 revolutions per minute, the periodicity being 60 cycles.

The lamp has two laminated wire cores, somewhat similar to the core of the Westinghouse ammeter, hung on a swinging arm, one of which plunges into the coarse wire series coil and the other into the fine wire shunt coil. One carbon rod only is used, and the carbon itself is about $2\frac{1}{4}''$ wide by $\frac{7}{16}''$ thick. The lamp runs for 42 hours with one set of carbons. The P. D. at lamp terminals is 50 volts and the current 10 amperes. For lamps for inside use a converter is attached to the high-pressure street wires which transforms the current to 50 volts and 10 amperes, so that 50 volts is the maximum pressure entering a building. With the 60-light machine the lamps when required for street lighting only, may be run in series without the use of these converters. In the 125-light machine the current is 30 amperes and the total E .M. F. 2100 volts, and, with this size, converters are used for all the lamps (whether for street or interior lighting), which raise the voltage from 17 volts per lamp to 50 and reduce the current from 30 to 10 amperes. These are made to carry one, three, or five lights each.

The machines are started upon short circuit, and when fully excited a switch is opened and the lamps thereby thrown into circuit. During a recent visit of the author's to one of the Westinghouse stations with a sensitive ampere meter attached, the total change in the current when the lamps were thus placed in circuit was less than two amperes, and this was only temporary. Provision is made by attachments on the dynamo and on the wires in the station to prevent the opening of the circuit.

LOW TENSION INCANDESCENCE DYNAMOS.

The Edison Dynamo (*Fig.* 5).

The type of low tension machines which has found most favour on this continent is the Edison as modified and improved by Dr. Hopkin-

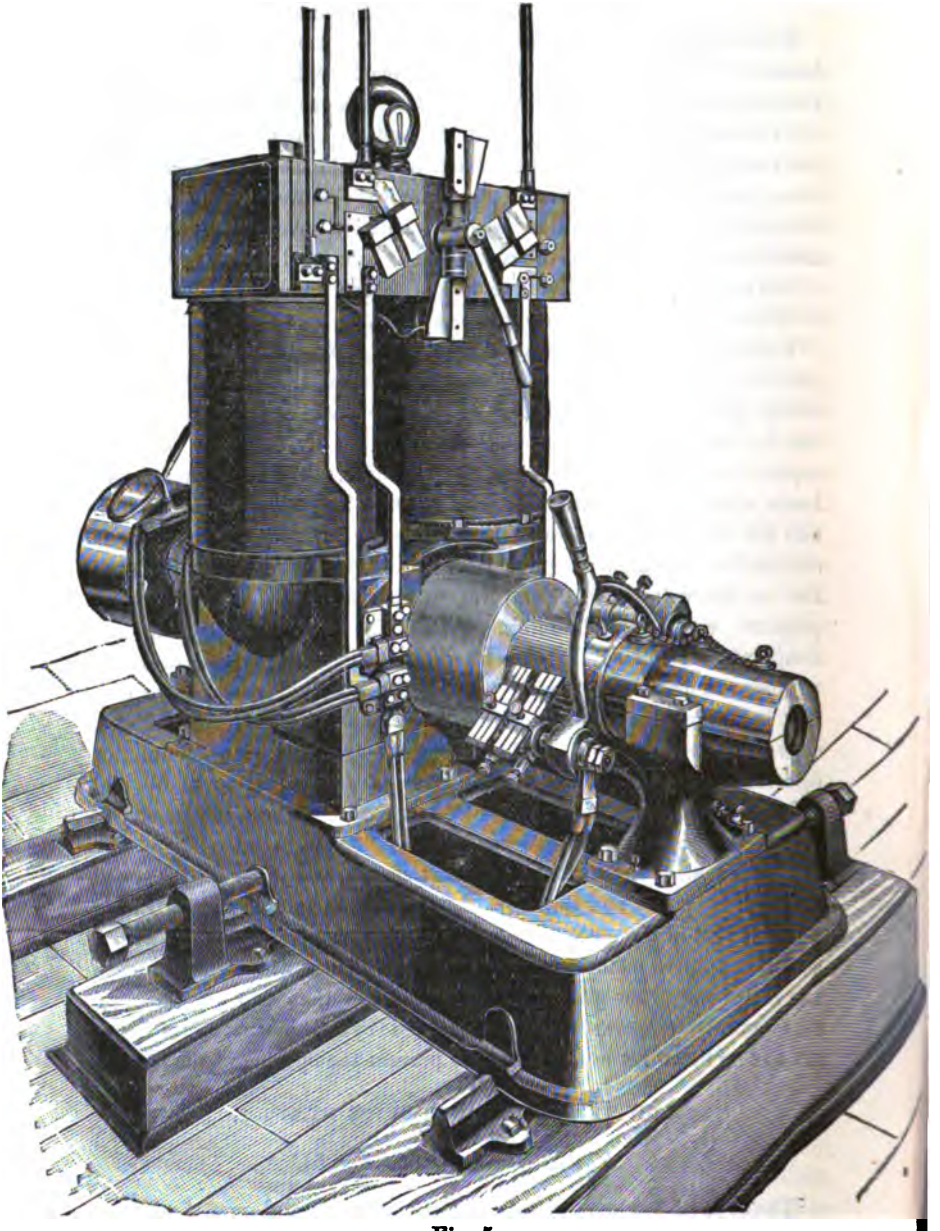


Fig. 5.

EDISON COMPOUND-WOUND DYNAMO.

son, and further perfected at the Edison Machine Works. Between the machines made by the Edison Co. in America and the Edison-Hopkinson machine made by Mather & Platt of Manchester there is this difference: the field cores of the Edison machine are made cylindrical and the armature core is still built up of iron discs bolted together; while the Edison Hopkinson machine has field cores, the section of which is a square between two half circles, and the armature discs are held together by nuts at each end of the core screwed on the shaft, thus giving the core a greater sectional area.

The Edison machines known as Nos. 10, 12 and 16 will serve to illustrate the general construction of Edison dynamos, and their relative proportions and weights. The No. 10 machine is made for an E. M. F. of 125 volts and a current of 200 amperes, but is hardly ever run at more than 200 amperes and 110 volts except for central station work. The total weight of this, the best running of all the Edison dynamos, is 3570 lbs. The two cast-iron field blocks weigh 600 lbs. The field cores which, as in all Edison machines, are of wrought-iron, are each $10\frac{1}{8}$″ diameter by $16\frac{1}{4}$″ long, and are connected by a massive wrought-iron keeper $10\frac{1}{4}$″ wide by 8″ deep by $26\frac{1}{4}$″ long. The field cores are wound with 220 lbs. of copper wire—110 lbs. on each limb. The wrought-iron in the armature weighs 220 lbs., the dimensions of the armature shell before winding are $8\frac{3}{4}$″ diameter by $16\frac{1}{2}$″ long, and the winding is a modified Siemens, taking 60 lbs. nett weight of copper wire. The diameter of the completed armature outside the bands is $9\frac{11}{16}$″ and the bore of the fields being $9\frac{15}{16}$″, there is a clearance of $\frac{1}{8}$″ all round. The speed of the machine is 1300 revolutions per minute. The resistance of the shunt coils is 37 ohms, and of the armature about .017 ohm cold, the shunt being thus about 2200 times the resistance of the armature. The output of this machine at 110 volts and 200 amperes is 6.13 watts per lb. gross weight, 77 watts per lb. of copper wire on the machine, and 333 watts per lb. of wire on the armature. There are 66 bars in the commutator.

The next two sizes will serve as a basis of comparison with the Royal Electric Co.'s Thomson incandescence machine and the two Brush incandescence machines, of which the particulars are hereafter given.

The weights and dimensions of the No. 12 Edison dynamo are as follows:—complete machine 4340 lbs.; the cast-iron field blocks weigh 800 lbs.—400 lbs. each. The field cores are $20\frac{3}{4}$″ long by $11\frac{1}{8}$″ diameter. The keeper is $27\frac{1}{2}$″ long, $11\frac{1}{8}$″ wide and $8\frac{3}{4}$″ deep. The armature core is $9\frac{11}{16}$″ diameter, and $18\frac{1}{4}$″ long. When wound the armature is $10\frac{1}{16}$″ diameter over bands, and the bore of the fields is

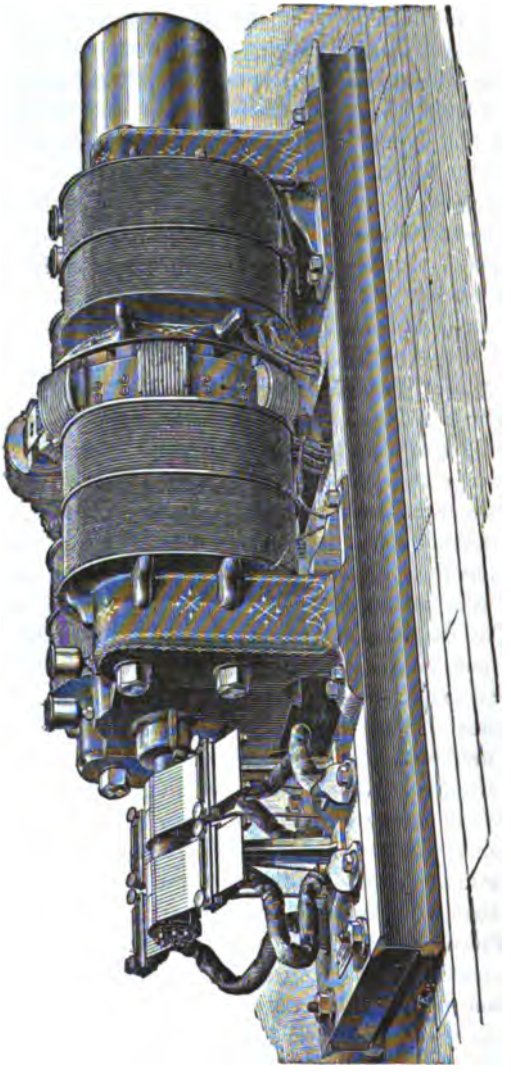


Fig. 6

BRUSH INCANDESCENCE DYNAMO. (Old Type.)

11¼, the clearance being $\frac{1}{32}$". 248 lbs. of wire are wound on the fields, and 84 lbs. of wire on the armature. The resistance of the shunt is 28.5 ohms and the resistance of the armature .011 ohm, the ratios being as 2600 to 1. At 110 volts and 240 amperes the output per lb. gross weight is 6.08 watts; for each lb. of copper on the machine it is 79.5 watts, and for each lb. of copper on the armature 314.3 watts. The speed is 1200 revolutions, and there are 58 segments in the commutator.

The No. 16 machine made for a current of 320 amperes weighs 6800 lbs. The field cores are 12¾" in diameter by 23½" in length. The keeper is 12¾" wide × 10" deep by 32½" long. The two cast-iron pole pieces weigh about 600 lbs. each, and are 28½ inches in length, parallel with the shaft. The bore of fields is $12\frac{7}{16}$" diameter; the armature core is $11\frac{1}{16}$" diameter by 20½" long, and when wound the finished armature is 12¼" over the bands, the clearance being thus $\frac{3}{32}$" all round. The weight of iron in the armature core is about 400 lbs., the number of commutator segments is 52, and the speed is 1000 revolutions per minute. Each field limb is wound with 160 lbs. of copper wire—320 lbs. on both. The armature is wound with 133 lbs. of copper wire, one-third the weight of the iron disc core. The resistance of the shunt is 22.7 ohms, cold, and of the armature between opposite bars .009 ohm, the ratios being as 2500 to 1. As a shunt wound machine run at 110 volts and 320 amperes the output is 5.18 watts per lb. gross weight: 77.7 watts per lb. total copper wire, and 264.66 watts per lb. of wire on the armature. When compound wound the series winding of this machine is composed of 10 wires in parallel, making 5 complete spirals round each limb outside the shunt winding. Its resistance is .001 ohm.

The armature cores in all the Edison machines are built up of the softest disc iron .006" thick, separated by thin manilla paper, and every fifth disc is more widely separated from the next by several thicknesses of the same paper. In the three machines above mentioned there are two layers of wire on the armature, of which each section is wound once around the core.

Brush low tension Incandescence Machines (*Fig.* 6).

The Brush incandescence machines are much lighter than the Edison for the same output. The new type which is being put upon the market has closed Gramme ring armatures connected to 60 segments in the commutator, the old type of machine, with only eight armature seg-

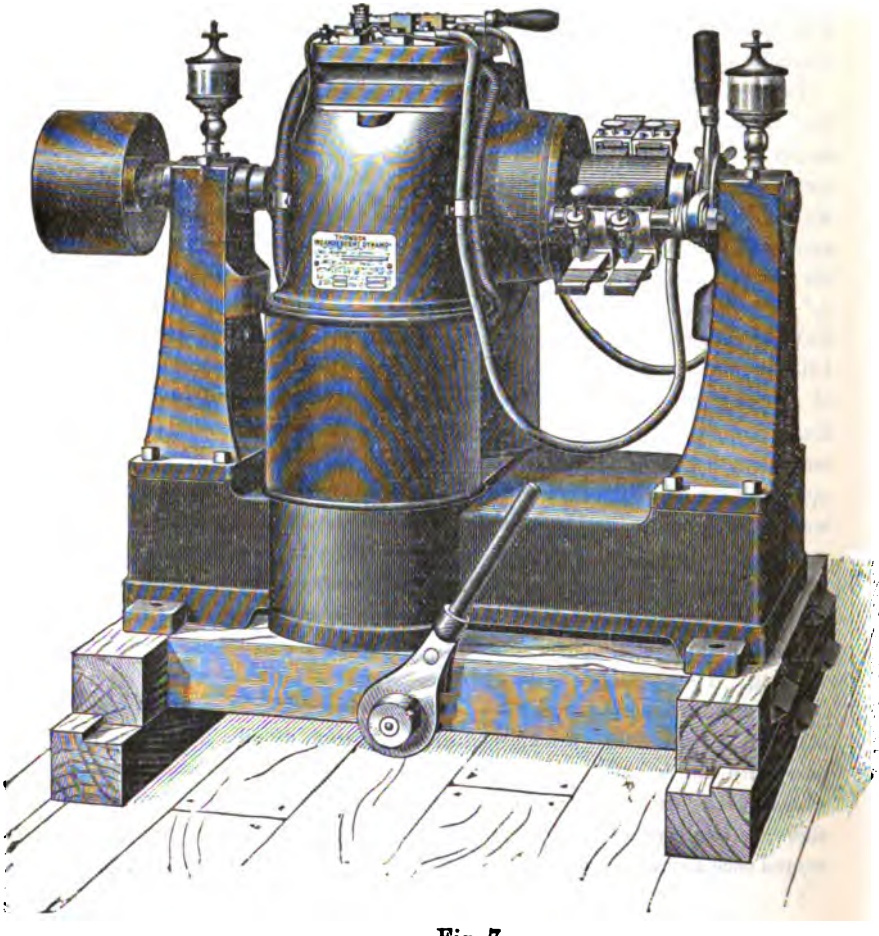


Fig. 7

THOMSON-HOUSTON INCANDESCENCE DYNAMO.

ments, as in the arc light machine, having been recently abandoned. Of this new type of machine particulars have not yet been given. The old 250 ampere machine weighs 2300 lbs ; the weight of iron in the armature, which is composed of laminated hoop iron, is 178 lbs., and the weight of iron in the fields is 400 lbs., the weight of copper on the armature is 148 lbs., shunt 360 lbs. and series coil 346 lbs. The gross weight of the 360 ampere machine is 3200 lbs; the weight of iron in the armature is 258 lbs. and the weight of copper is 184 lbs: on the fields there are 444 lbs. of copper in the shunt and 460 lbs. in the series coils. The output of the 250 ampere 105 volt machine is 11.4 watts per lb. gross weight: 30.73 watts per lb. of the total copper wire, and 177.36 watts per lb. of wire on the armature. For the 360 ampere 105 volt machine these figures are 11.81 watts per lb. gross weight; 41.81 watts per lb. of copper on machine, and 205.43 watts per lb. of copper on the armature. The speeds are 1200 revolutions and 1100 revolutions per minute respectively.

The largest Brush machine, first made for the Cowles Smelting Co. of Lockport, N. Y., is equally adapted for the smelting of aluminum or the production of current for incandescent lights. Its capacity is 3200 amperes at 86 volts. It has 5424 lbs. of copper on the fields and 1600 lbs. of iron and 825 lbs. of copper in the armature. The total weight of the machine is 22,000 lbs., and the output 12.51 watts per lb. gross weight ; 44 watts per lb. of the total copper wire, and 332 watts per lb. of wire on the armature.

Thomson Incandescence Dynamo (*Fig.* 7).

This incandescence machine, which is made in Canada by the Royal Electric Co., is very similar to an inverted Edison dynamo. The wrought iron keeper is dispensed with, the bed casting forming the yoke between the field cores. The armature is built up in the same manner as in the Edison machine, of wrought-iron discs, but thicker, and instead of paper insulation between them, vulcanized fibre is used. The 250 ampere 110 volt Thomson machine weighs 5260 lbs. complete. The armature core is $14\frac{1}{2}$" long by $11\frac{1}{2}$" diameter, and is wound with $130\frac{3}{4}$ lbs. of No. 4 wire to $12\frac{3}{4}$" diameter over the bands. The bore of the fields is 13", thus allowing a clearance of $\frac{1}{8}$" all round the armature. There are 76 segments in the commutator. The field cores, which are of wrought iron, are $10\frac{3}{4}$" diameter by $12\frac{3}{4}$" long, and are wound with $120\frac{1}{2}$ lbs. of No. 15 wire, and the series coil of four No. 8 wires weighs 62 lbs. The speed of the machine is 1300 revolutions per minute.

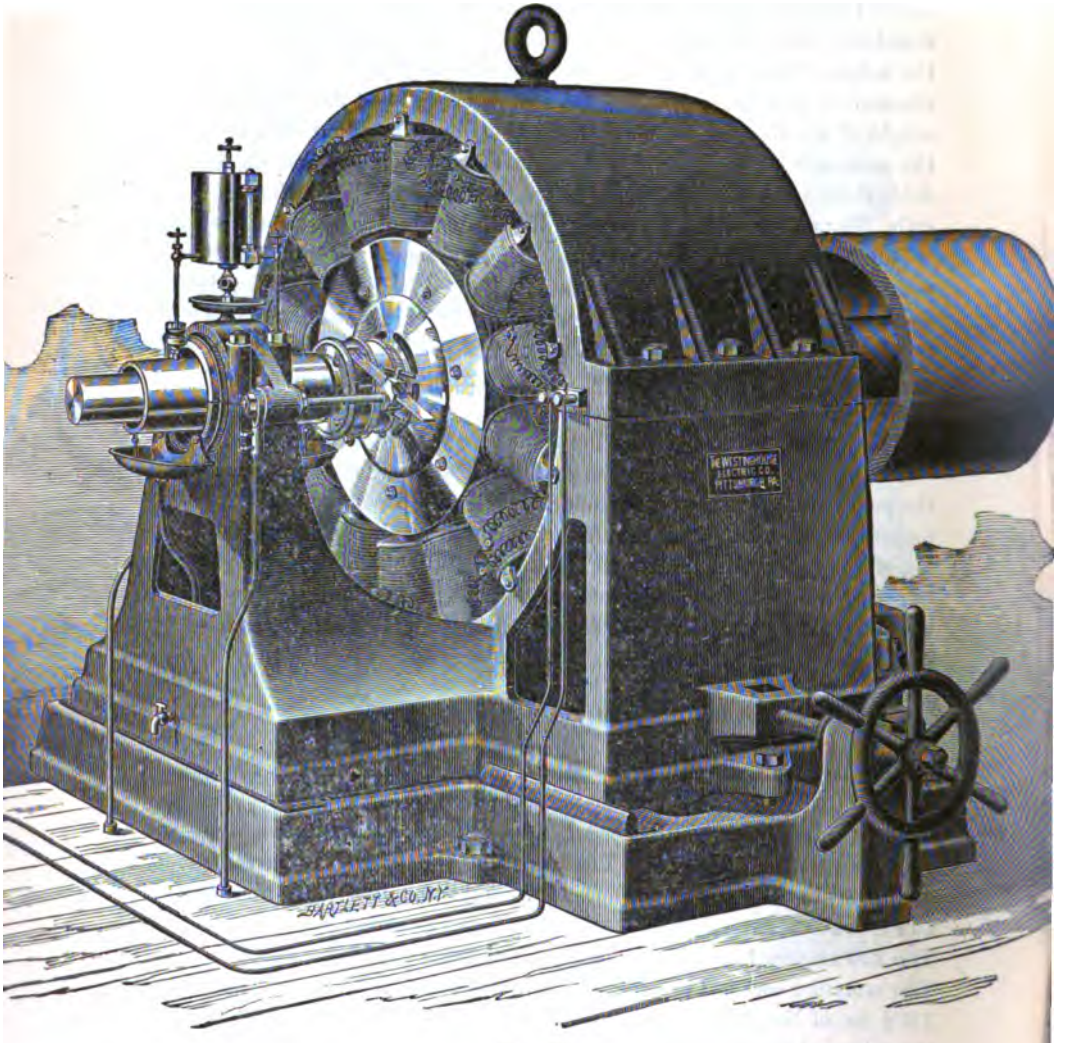


Fig. 8.

WESTINGHOUSE A. C. DYNAMO.

The output is, therefore, at full load 5.23 watts per lb. gross weight; 87.79 watts per lb. of copper wire on the machine and 210.3 watts per lb. of wire on the armature. One peculiarity of this machine is the manner in which the series coils are wound over the armature itself and not over the field limbs as in other dynamos. The regulation of the machine is not perfect, but is fully equal to that of the compound-wound Edison dynamos.

ALTERNATING CURRENT DYNAMO MACHINES.

Westinghouse Dynamo (*Fig.* 8).

In a description of alternating current apparatus, the first place is due to the Westinghouse Electric Co., of Pittsburgh, organized in 1886, the pioneers on this continent in the supply of the A. C. system of distribution of electricity.

The Westinghouse 1500-light machine weighs 9750 lbs. complete. The armature, which is built up of laminated discs of soft iron, is in the form of a hollow cylinder, $20\frac{7}{8}$" in diameter and 21" long, and weighs 1440 lbs. It is wound with 30 lbs. of No. $10\frac{1}{2}$ B. & S. gauge wire, and its weight complete is 1600 lbs., including the shaft. The total weight of the castings in the field and bed plate is 6838 lbs. The weight of copper wire on the field bobbins, which are twelve in number, is 1257 lbs. The current from the machine at full load is 75 amperes, and the pressure 1050 volts. The output is thus 7.7 watts per lb. of gross weight: 58.27 watts per lb. of copper wire on the machine, 2500 watts per lb. of wire on the armature. The speed of the machine is 1375 revolutions per minute, and the periodicity 136. The exciting current is 14 amperes at 110 volts pressure, equivalent to 1540 watts, or nearly 2 E. H. P.

Brush A. C. Dynamo (*Figs.* 9 *and* 10).

This dynamo and the other details of the Brush Company's alternating current system are the invention of Mr. Gustave Pfannkuche, who, as will be observed, has made a radical departure from the usual construction of dynamos and converters hitherto adopted in this country, and obtained results in point of efficiency and general excellence of design, not surpassed, if equalled, in any other system.

The machine shown in the engravings is the 1000-light alternator. Like all the Brush A. C. dynamos, it is intended to be run at from 2000 to 2200 volts. This machine delivering 30 amperes at that pressure runs at 1100 revolutions per minute at full load, at

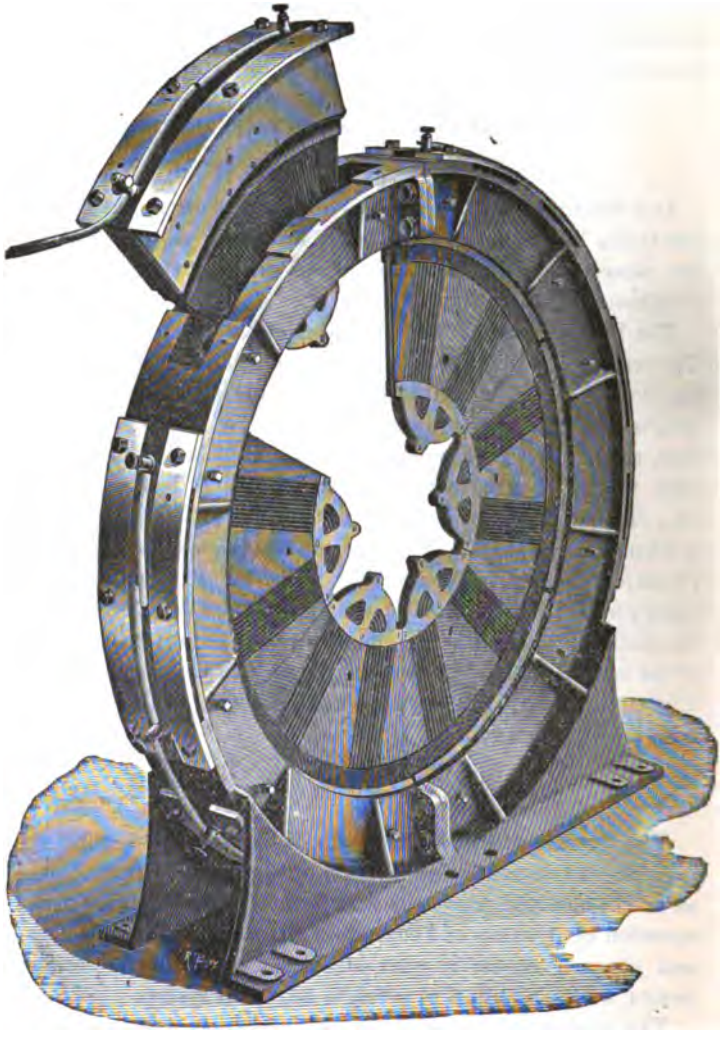


Fig. 10.

ARMATURE OF BRUSH A. C. DYNAMO.

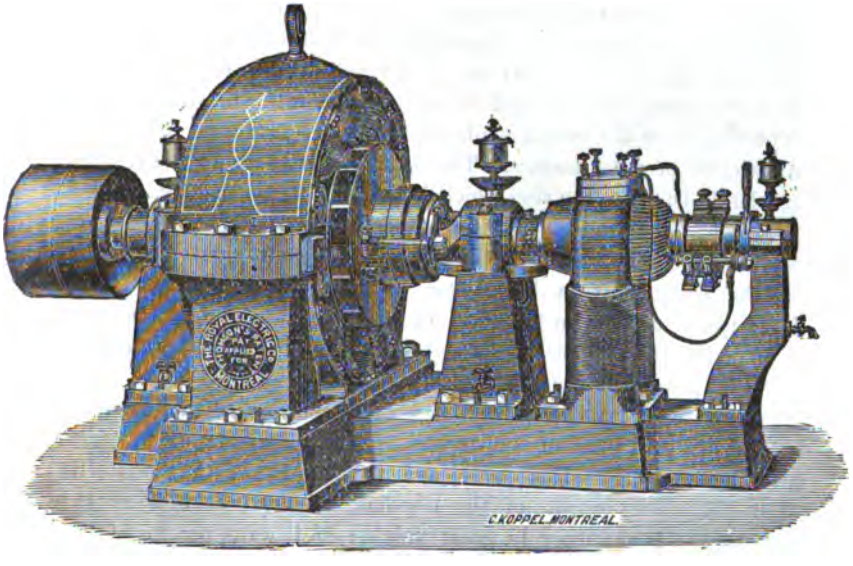


Fig. 11.

ROYAL ELECTRIC CO.S A. C. DYNAMO.

which it takes 100 H. P. to drive the alternator and exciter. The exciting current of 22 amperes and 135 volts is supplied by a small Brush arc light dynamo. The regulation is effected by sending part of the current from the exciting dynamo through a shunt box of varying resistance operated by hand. Very little regulation, however, is required, as the machine is nearly self-regulating from no load to maximum load. The armature (Fig. 10) is stationary and the fields revolve, this being the only A. C. machine in America so constructed. Such a construction has many advantages: in the first place the revolving part has only a low tension current passing through its coils, and being heavy and perfectly balanced acts as a fly wheel and regulator when from any cause there is a tendency in the prime motor to slacken speed. The wires from the switchboards are permanently attached to the ends of two coils of the armature. The armature coils are light and independently bolted to the ring which holds them in position between the field bobbins. Should an accident happen to one of the armature sections, the latter may be replaced in five minutes by one man, the weight being only a little over 20 lbs. The armature core is composed of fibre in segments on which are wound copper ribbons insulated by silk and shellac. The total weight of the armature ribbon is 63 lbs., and of the complete machine 5120 lbs.

There are 12 cores of alternating polarity on each side of the field wound with 618 lbs. of copper wire. These cores are of wrought-iron bolted to two iron plates, and the weight of the twelve is 456 lbs. The output of the machine, 60,000 watts, is at the rate of 11.71 watts per lb. gross weight: 88.1 watts per lb. of the total copper on armature and cores, and over 952 watts per lb. of the copper ribbon on the armature.

The Royal Electric Co.'s Dynamo (*Fig.* 11).

Sometimes the machines of the Royal Electric Co. for A. C. work are made with the exciter on the same shaft as shown in the cut, but more frequently the exciter is separate. In the 1200-light dynamo with separate exciter, the active iron in the fields weighs about 3400 lbs., and the iron rings of the armature (which is a hollow cylinder built up of laminated wrought iron) weigh 1250 lbs. The radial depth of these rings is 5″. When turned up ready for winding the armature is $24\frac{5}{8}$″ diameter and $18\frac{1}{2}$″ long. The diameter when wound is $25\frac{1}{8}$″ over the bands, and, as the internal diameter of the field bobbins is $25\frac{1}{2}$″, there is a clearance of full $\frac{1}{16}$″ all round. The fields are wound with 845 lbs. of No. 8 B. & S. gauge wire; the armature winding con-

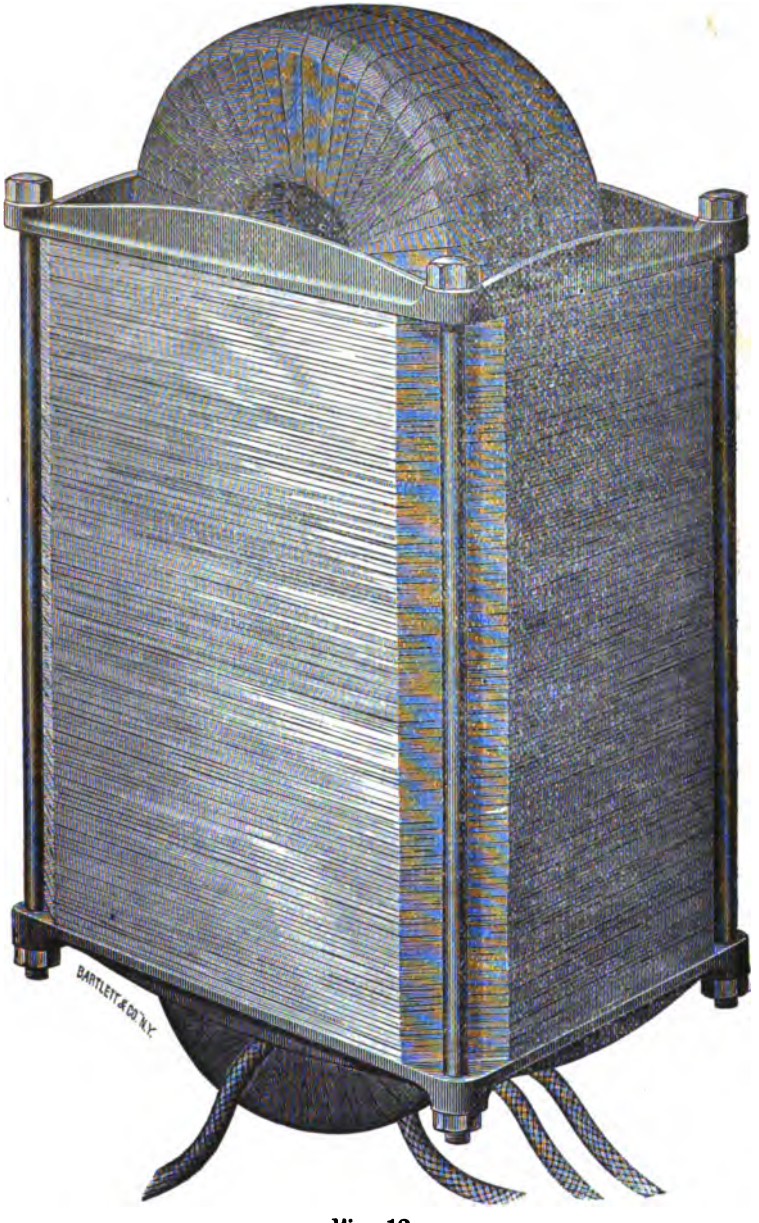


Fig. 12.

CORE OF WESTINGHOUSE CONVERTER.

sists of 32 lbs. of No. 11 B. & S. gauge wire. The speed of the machine is 1200 revolutions per minute, and the exciting current at full load is 24 amperes and 90 volts—say 2160 watts or nearly 3 E. H. P. The standard output of the machine is 70 amperes and 1020 volts, or 7.5 watts per lb. gross weight: 81.41 watts per lb. of the total copper wire and 2231 watts per lb. of the wire on the armature.

RATE OF ALTERNATION OR PERIODICITY.

In the Brush dynamo the periodicity is 110, while in the Fort Wayne, Westinghouse and Thomson-Houston machines the periodicity is from 125 to 136.

The European practice as to the rate shows considerable variation Messrs. Ganz & Co., of Buda Pesth, in the Zipernowsky system use 42 cycles; Mr. Ferranti uses 68; Lowrie-Parker work their machines at 80; and Mr. Mordey runs his at 100.

CONVERTERS.

Westinghouse Converter (*Figs.* 12 *and* 13).

The Westinghouse converter is of the shell type. In the 40-light converter, the core is built up of plates .017 inch thick, of which the total weight is 81 lbs. The primary winding of No. 16 wire weighs 10½ lbs., and the secondary wire is No. 3 gauge, 13¼ lbs. in weight. At 50 volts and 40 amperes this converter gives an output of 19.09 watts per lb. of active material. The P. D. required between primary terminals is 1000 volts, developing an E. M. F. of 50 volts at the terminals of the secondary coil.

Recent tests by Dr. Louis Duncan, of John Hopkins University, show 95 per cent. efficiency in a 40-light converter at full load, and only 84 watts loss with no load, and 90, 87.6, 83.3, and 70.7 per cent. efficiency in a 20 light converter at full, three-quarter, half and quarter loads respectively.

Brush Converter (*Figs.* 14 *and* 15).

The Brush converters are of the core pattern, with the exception of the two of smallest size. The iron wire in the core of the 50 light converter weighs 92 lbs., the primary wire weighs 20 lbs., and the secondary winding 11 lbs. At 100 volts and 30 amperes its output is thus 24.39 watts per lb. of active material. The case weighs 100 lbs. The 75-light converter core of iron wire weighs 115 lbs., primary winding of copper wire 21 lbs., and secondary winding 15 lbs. At 100 volts and 45 am-

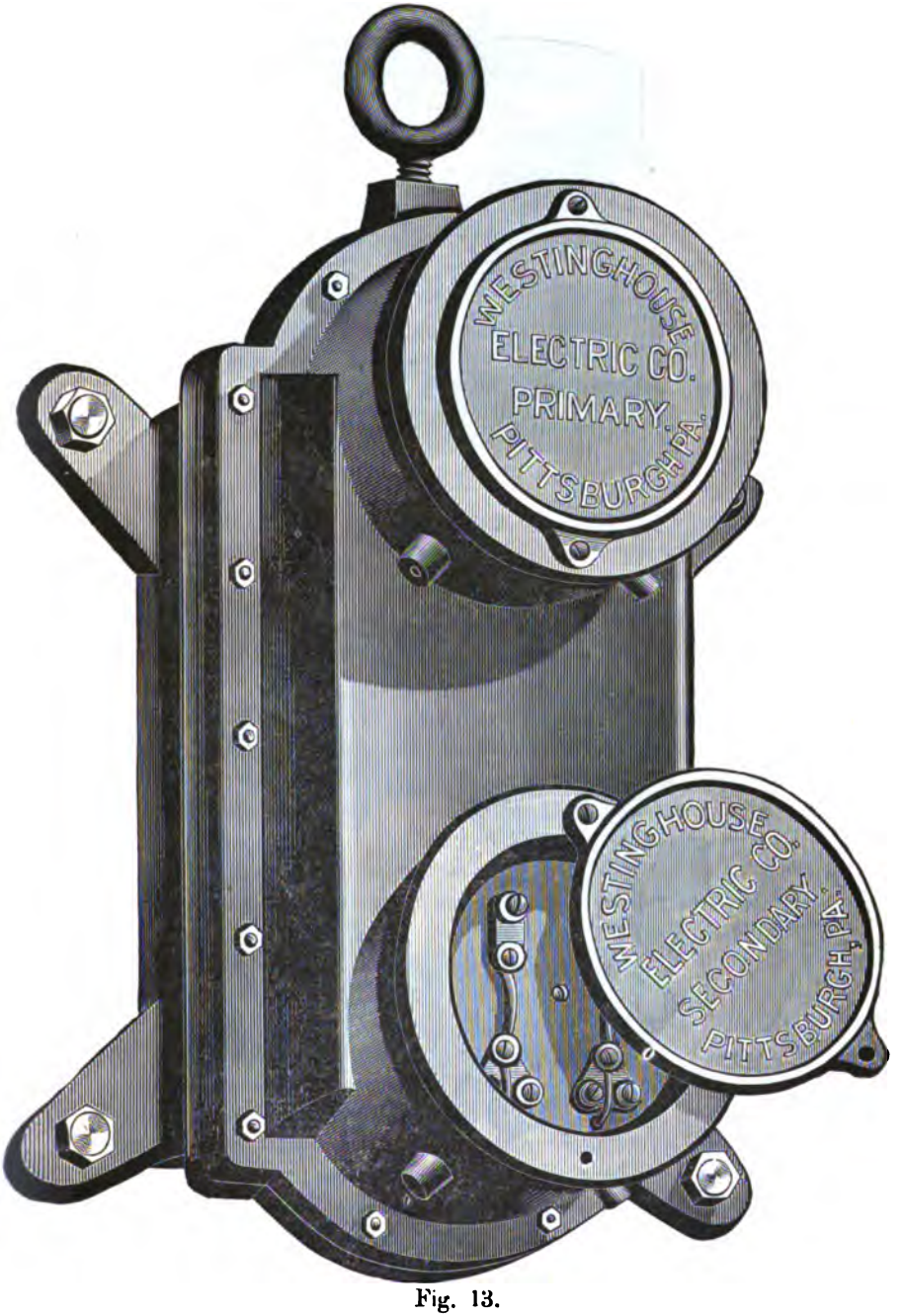


Fig. 13.

WESTINGHOUSE CONVERTER IN CASE.

Fig 14.

20 LIGHT BRUSH CONVERTER IN CASE.

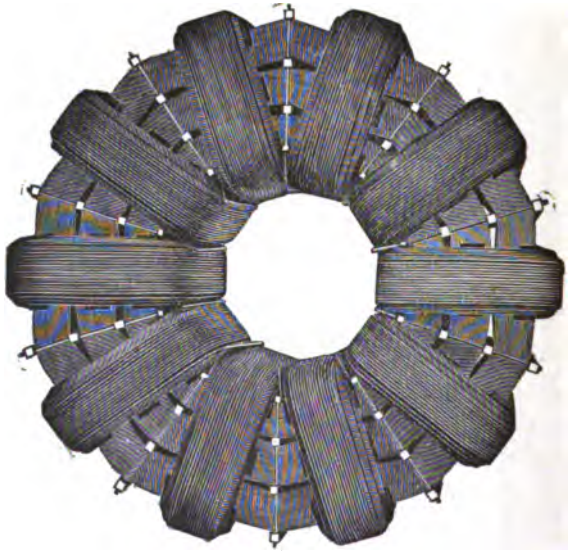


Fig. 15.

LARGE SIZE BRUSH CONVERTER (Case removed).

peres the output is 29.8 watts per lb. of active material. The case weighs 110 lbs. These converters are made in standard sizes of 5, 10, 20, 30, 40, 50, 75, 125, 250 lights and up to 1000 lights capacity. They are also made for primary circuits of 1000 volts pressure with a ratio of conversion of 10 to 1 or 20 to 1. The core consists of the finest Swedish iron wire, insulated by cotton winding or braiding wound into an octagon form, by having pieces of wood placed under and through the coils, as shown. The secondary wires are then wound over the sections between the wood blocks with insulated pads between them and the iron wire at the corners. Over the corners of the secondary winding are placed other insulating pads, over which are then wound the fine primary wires. There is thus an air space for insulation all round the different coils except at the corners where the wires lie on the insulating pads. The efficiency of a 75-light converter varies from 98 per cent. with 75 lights attached, to 93 per cent., with 38 lights.

THOMSON CONVERTER.

The Thomson converter, manufactured by the Royal Electric Company in this city, is similar in construction to the Westinghouse. The following are the particulars of the 30-light size: Iron discs, 108 lbs. primary wire, 920 feet No. 18 B. & S. gauge, 4¾ lbs.; secondary wire, 44 feet No. 8 B. & S. gauge, two in parallel, 4 lbs.; total active material, 116¾ lbs. with an output of 13.20 watts per lb.; case, 59½ lbs.; weight complete, 176 lbs.

METERS.

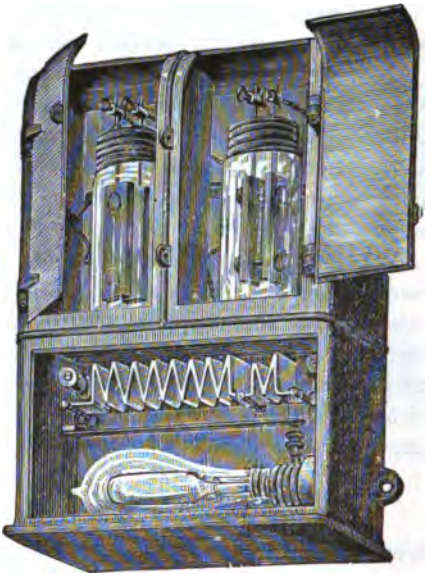
Edison Meter (*Figs.* 16 *and* 17).

In the Edison system of distribution an electrolytic meter has been employed. A disadvantage connected with its use is that nobody except an employee of the company can find out what the meter has registered, and even he has to take every precaution in the washing and drying of the electrodes, and in their accurate weighing in a chemical balance. This meter has been very extensively used, and has evidently given fair satisfaction, but the following statements from some of the superintendents of Edison stations show that satisfaction is not general:

"The confidence is fully as great as in gas meters."

"They [the customers] have as much confidence in the Edison meter as in the gas meter, and probably a little more."

"The meter to our customers is a blank, and it becomes a question of confidence in the meter man."



E DISON METER. Fig. 16.

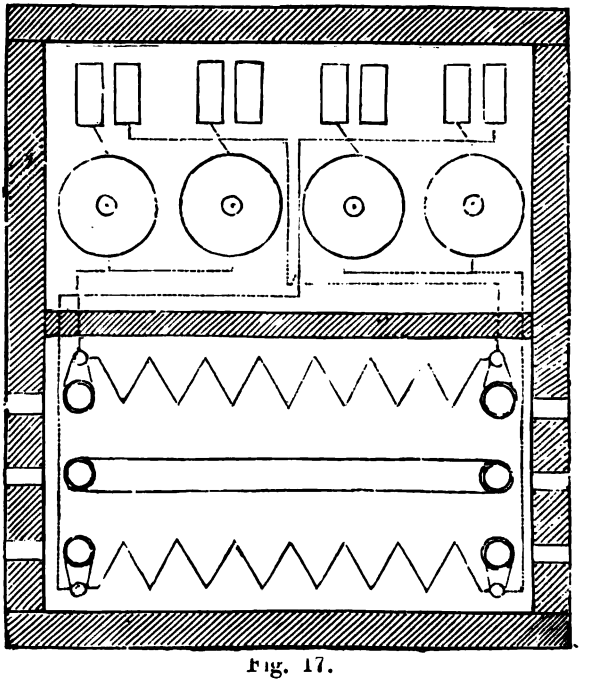


Fig. 17.

CONNECTIONS OF EDISON 3-WIRE METER.

Fig. 18.

ARON'S 3-WIRE METER.

"Our meters here are a great deal of trouble owing to the number we have in use, but still we could not get along without them."

Sir D. Salomons, in the last edition of his work on electric lighting, describes the Edison meter as a thing of the past.

It is but fair to the Edison Company to say that they do not recommend their meters being used in stations of less than 1000 lights capacity.

Aron Meter (*Figs.* 18 *and* 19).

The Aron three-wire meter (Fig. 17) is used in all the large Edison stations, and by some other companies in Germany. It is a most admirable and reliable instrument, and it is one from which the consumer himself can learn what he is using. The one shown in Fig. 18 is applicable to the two-wire direct and A. C. systems. The registering apparatus consists of two sets of clockwork which will run forty days with one winding, but which it is intended to wind up every thirty days, when the readings are taken. The pendulum on the left is an ordinary pendulum uninfluenced by the current, but that on the right consists of a coil of very fine wire, which is connected direct to both the positive and negatives wires of the system, while one of the main wires, either the positive or negative, forms a solenoid through which the main current passes, enveloping the fine wire pendulum core.

Before any current is passed through the meter, it should be tested in place to see that the pendulums swing synchronously. If they do not, the indications of one pendulum will gain upon those of the other. The exact adjustment to perfect synchronism is obtained by raising or lowering the weight on the left hand pendulum. If found correct the current is passed through the meter, and the right hand pendulum's movement being accelerated by the action of the current, causes the registering gear to work.

The chief obstacle in the way of the more general employment of this meter is its comparatively high first cost, but it appears to be well worth the money.

Shallenberger Meter (*Fig.* 20).

The Shallenberger meter is the one which has been most extensively used in America for the measurement of alternating currents, having been exclusively used in the Westinghouse stations, and being now largely used in those of other companies. About 12,000 are now in use. It is simply a small alternating current motor with registering gearing, and attached vanes placed on the shaft to retard the movement to a degree necessary for adjustment and regulation. Its chief

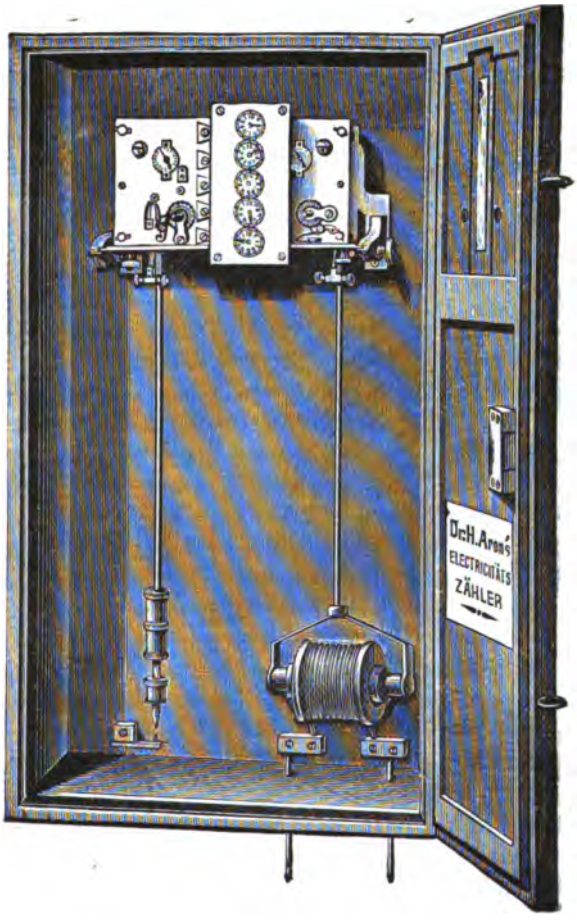


Fig. 19.

ARON'S A. C. METER.

disadvantage is that it does not work readily with a small current, but as this tells against the company and not against the consumer, the latter will not probably have any objection to it. This meter will be better understood by examination of the sample on the table.

Alternating current meters have also been made by the Fort Wayne Electric Co. and the Thomson-Houston Electric Co.; but the latter is not yet on the market, and as the author has no experience of either he prefers not to describe them, but would refer members to the "Electrical World" or "Electrical Engineer" for full particulars.

STORAGE BATTERIES.

Storage batteries have not been applied on this continent to any such extent as they have been in Europe. Wherever they are employed except for propulsion of about a dozen street railway cars, perhaps fewer, it has been for the purpose of securing light after engines and dynamos have been stopped at night, and for railway car lighting. For the latter purpose they have not hitherto been a success, and have been discontinued on the Pennsylvania Road, on the Canada Atlantic and on the Grand Trunk Railways, the Julien battery having been used in these cases. On the Intercolonial Railway a great number of cars have been fitted up with these batteries, and it is said several additional charging stations are to be erected, it having been found that the two at present in operation, one at Levis and the other at Moncton, together with such current as may be obtained at Halifax, N.S., and Montreal, have been insufficient, or otherwise expressed, the capacity of the batteries supplied has not been enough to last during the runs between the various stations. The fact that the coal oil lamps, which were wisely left in position, are used on nearly every trip, proves the inadequacy of the batteries which have been supplied for this work.

Outside of these plants storage batteries have been used in five or six places in Canada, among which may be mentioned McGill College, the lights there being run from a Gibson battery in the basement. The battery is charged from a small shunt wound dynamo driven by an Otto Gas engine made by Crossley Bros. of Manchester.

A PRIVATE INSTALLATION.

The same kind of plant and the same kind of battery are used in the residence of Mr. F. R. Redpath, the arrangement of which is shown in Figs. 21–24. The plant is in the basement of the house. The gas engine is an Otto made by Messrs. Schleicher, Schumm

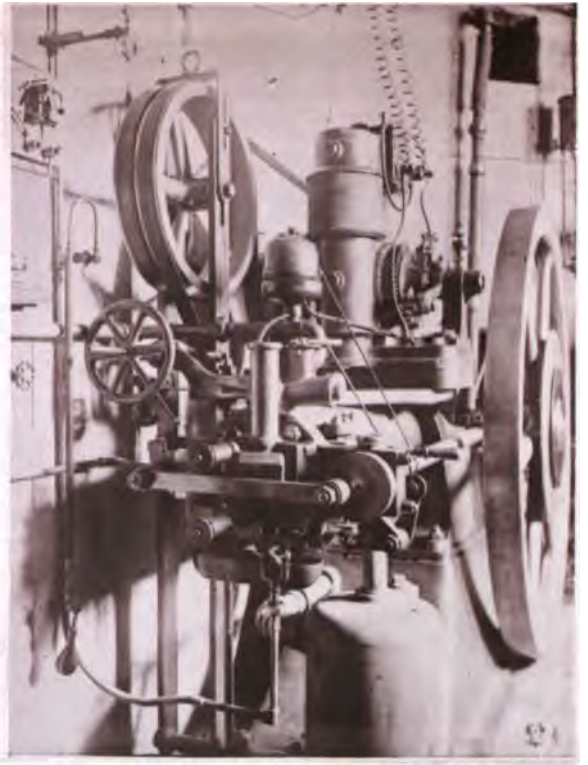


FIG 21.

FIG. 22.

MR. F. R. REDPATH'S INSTALLATION.

Fig. 23.

Fig. 24.

Mr. F. R. REDPATH'S INSTALLATION.

& Co., of Philadelphia, and is the steadiest running gas engine in Canada. Its weight, with two 54-inch fly wheels, is about 3200 lbs. It indicates 3.9 H. P., with a gas consumption of 26 cubic feet per H. P. per hour. Over the cylinder is a cast-iron saddle, on which the dynamo, a shunt wound machine made by Holmes & Co., of Newcastle-on-Tyne, England, is placed, there being just one quarter of an inch clearance between the rims of the fly wheels and the ends of the dynamo bed. Behind the dynamo and attached to the bed of the engine are two wrought-iron adjustable arms carrying the countershaf and idler pulley. The dynamo pulley is therefore between the idler and the fly wheel of the engine, is double crowned and is lapped over nearly the whole circumference by two belts as shown. The slip is less than 2 per cent. The speed of the engine is 180 revolutions per minute. The dynamo weighs 430 lbs., and the idler pulley and countershaft 100, so that the total weight of engine, dynamo and driving gear is 3800 lbs. A box 7′ 4″ × 2′ 8″ × 5′ 2″ would cover engine, dynamo, belting, idler pulley and countershaft, and the whole might be thus shipped to any distance completely set up ready for connection of gas and exhaust pipes. The arrangement of the plant was designed by Mr. Redpath, and is most compact and ingenious.

There are 42 cells of Gibson battery, capacity 150 ampere hours, and they are connected in two sets of 21 each in parallel, the changing current being 33 amperes at from 45 to 55 volts pressure. These cells are ranged on shelves in the engine room. The plates in this battery are placed horizontally instead of vertically as in other batteries, and have thus the advantage of being less liable to short circuiting through paste falling between them as it does in vertically arranged plates. A slight disadvantage is that the internal resistance is higher than some other forms of battery owing to the plates being further apart; but this is compensated for by the longer life of the Gibson, the makers guaranteeing to keep it in order for ten per cent. per annum of the first cost. The electrolyte used is dilute sulphuric acid with the addition of sulphate of soda, the density of the combined solution being 1.220. This battery will stand heavier charging than any other, and has frequently been charged with a current of 75 amperes; but the most economical practical charging rate is about 30 amperes. In charging the current is measured by Weston ammeter and the pressure by a Weston voltmeter. There is also another Weston voltmeter in the library upstairs, and underneath it a resistance switch of German silver in series with the battery, by which the pressure in discharging is regulated, as the battery, when first connected to the lamps

after charging, is higher in E. M. F. than when nearly discharged, the lamps used being of course of such voltage that they will give their full light at the lowest pressure to which the battery in practice is reduced. The maintenance of perfectly uniform light is thus under control from Mr. Redpath's arm chair.

This is the first and only complete private installation for residential lighting in Canada, and was first started five years ago, shortly after the visit of the British Association to this country.

VALLEYFIELD AND BARRIE CENTRAL STATIONS.

Let us describe briefly and compare these central stations, both constructed by the writer, and good samples of their respective classes. Both have water power, but the first is on the Edison three-wire system and the second is a Brush A. C. plant. In Valleyfield the power is in the heart of the town and in the centre of distribution, so that it is in the most favourable position for economical distribution by low tension, and the wire used is as small in area as consistent with even voltage at the lamps and greatest efficiency of the plant. Both stations were built with rooms for the man in charge over the dynamo room. The running expenses are the same or about the same in both places. Probably no other stations of similar capacity in the world cost less to run, the total annual expense in each being less than $1600. The capacity of both stations is about the same, say 60,000 watts. The Valleyfield station complete cost $40,000, including building, water-wheels and flume. The Barrie station, with the same items, cost less than $22,000, including over $3000 for the wire leading into town from the station, five miles distant. In the Barrie plant heavily insulated wire is used throughout the 24 miles of street wiring, and rubber-covered wire in all buildings, whereas bare wire is used at Valleyfield for street wiring, and fire and weather-proof wire for inside work. House wiring in Valleyfield is all cleat work: most of that at Barrie is concealed, the lights in the latter place being principally in private houses and placed on brass fixtures, whilst at Valleyfield drop cords are used exclusively. The pressure in the houses in Valleyfield is generally 220 volts, the three wires being carried in in all cases where this system is used, in order to maintain as even a load as possible on both sides of the circuit. In Barrie the pressure is 93 volts on the lamps in the houses, and nothing higher than 98 volts can ever enter them. The charge for current averages at Valleyfield $9 per light a year, and at Barrie $7.50. This means that, making due allowance for all contingencies in both cases, the

Barrie plant will pay its shareholders better than the Valleyfield plant will, while the customers pay $1.50 per light a year less. In the Barrie station Westinghouse meters are used on the premises of the largest consumers, and these can be read by the consumer as well as the meter man, the cost of operating the station is not increased, the man who attends to the wiring of the buildings in town and to collection of accounts taking the readings; while if the Edison meter be used at Valleyfield, another man will require to be employed to attend to the meters solely, and his wages will have to be added to the operating expense and thus reduce the net revenue.

The respective sizes of wire used in both stations is worthy of study. At Barrie the loss in the feeder is 14½ per cent. at full load, nearly the same as at Valleyfield. The length of feeder at Barrie is 10 miles for the complete circuit, and the size of wire No. 4 B. W. G. At Valleyfield the feeders are three in number and three in a set; the longest is less than two miles for the complete circuit, and the size of the outside wires No. 000 B. W. G. The No. 4 wire used at Barrie weighs 985 lbs. per mile, including insulation, and the No. 000 bare wire at Valleyfield weighs 2886 lbs. per mile.

It may be and has been said that in the one case there is a perfectly safe low tension system, while in the other, to use the pet phrase of the paid advocate of low tension, the New York State Electric Executioner there is the "Deadly Alternating Current." That is admirable as a trade trick, but even the Edison Company now advertise that they are prepared to supply A. C. plant to all who desire it. Either there is less danger in the A. C. system than they would have the public believe, or they are ready to subordinate principle to pocket in the contest. To alter slightly a phrase from Dickens' "Holiday Romance," the Edison people have been advising the public to "Prohibit the use of the alternating current system on the ground of humanity as it makes ours too expensive." In an article on the subject, Sir William Thomson, the greatest living authority on electrical matters, says :

"*In passing I may remark that* 100 *volts in the house is perfectly "safe to the user, whether the current be alternating or continuous, as "is proved by large and varied experience in England.*"

It must be freely admitted that the accidents reported from New York were real and not invented for sensational purposes, but it must also be acknowledged that in no other city in the world is there such an organization as the Board of Electrical Control, to which appointments are made by political influence only, regardless of qualification,

and one of whose advisers is, or was, an individual whose business it was for the past two years to discredit the alternating system, for which service he was well paid. In no other city in the States or Canada is there such bad construction of overhead conductors as there was in New York. The under-ground construction there is nearly as dangerous on account of existing grounds on the wires and leakage of current and the consequent liability to cause explosions of gas in subways, as has already been repeatedly done, besides turning the paving stones into "a molten mass."

Furthermore, the insulation of the overhead wires, which have been in use in some cases over eight years, had rotted off, being of the quality known as "Underwriters," or "Undertakers" if you will.

Four deaths have occurred in the whole history of electric lighting in Canada from shocks of electricity, and two of these were the result of bad insulation of wires and faulty construction by a purchasing company doing its own work, without employing anybody having any knowledge of the business, in order to cheapen the first cost of the plant, and which purchased a job lot of poorly insulated wire, and ran two dynamos in series with 100 arc lamps in circuit at a tension of nearly 5000 volts. The current used on that system was a continuous one, not a pulsating high tension current as stated in a circular which some of you may have received.

Reverting to the main subject: Thirty wires radiate from the Valleyfield station; one pair carry the current from the Barrie station. In the Barrie station the pressure of primary current is the highest which has yet been used in this country, being about 2100 volts average on the feeder. This pressure is raised or lowered by increasing or decreasing the exciting current according to the load shown on the central station ammeter, which is graduated to single amperes, and is indicated by a Cardew voltmeter, which, as elsewhere mentioned, is attached through a converter to the armature. Instead of having a compensator as is used in the Westinghouse system, a table of loads and the corresponding pressures to be carried at the station is used. This method, though of course not absolutely perfect, owing to the rise of current with increase of voltage and vice versa, answers very well. The Cardew voltmeter in the company's office in town, which is an excellent check upon the dynamo attendants' work, shows an average variation of two volts only in a night's run. The mains in town, which aggregate nearly 14 miles in length, are calculated for a loss of only 2 per cent. at full load, which gives a difference of $\frac{3}{8}$ of a volt per lamp up or down from the standard. The house wires, which are insulated with

Fig. 25.

WESTON VOLTMETER.

rubber and tape are calculated for one per cent. loss only at full load As most of the lights are taken in private residences, where the whole number are hardly if ever in use at one time, the loss of light through resistance of the house wiring is practically nil.

MEASURING INSTRUMENTS.

The Ayrton and Perry instruments have been used to a very considerable extent in this country, and until recently were the most accurate of all really portable electrical measuring instruments. There is a sample on the table before you. They are only suited for direct. currents, and are open to the objection that they have considerable friction and a high temperature error if kept in circuit, which they should never be except only for a few seconds when taking readings.

The Weston voltmeter is shown in Figs. 25 and 26. These voltmeters have the great advantage of extreme accuracy and very high resistance, averaging about 20,000 ohms, so that the quantity of current passing is extremely small. They may be kept continuously in circuit without any material variation in their readings. They require careful handling, of course, as do all electrical instruments, but they are the most accurate and reliable of all portable testing instruments for continuous currents. The voltmeters contain a calibrating coil by which their constancy can be at all times tested. The writer has used quite a number of these instruments which he has checked with each other, and has sometimes compared the higher and lower scale by taking the P. D. difference between terminals of single cells of secondary batteries, and then, putting the whole of the cells in series, compared the reading of total E. M. F. of the battery. Several tests of this nature have come out within one quarter of a volt. The calibrations are in single volts on the higher scale, and thirtieths, twentieths or tenths of volts on the lower scale. The ammeters read to tenths of amperes in the small sizes. In both the divisions of the scale are so wide that one quarter of these values can be read with perfect ease.

For the most perfect readings by these instruments they should be set quite level, and five feet away from any other instrument, or from any mass of iron or steel, and so placed that the index will point due west when at the centre of the scale, but these precautions are not necessary for ordinary testing of pressure in build ings, as the error can seldom be more than ½ volt, if otherwise placed.

The Cardew volt meter (Fig. 27) is used for both direct and alternating currents, and is made to be used either vertically or horizontally.

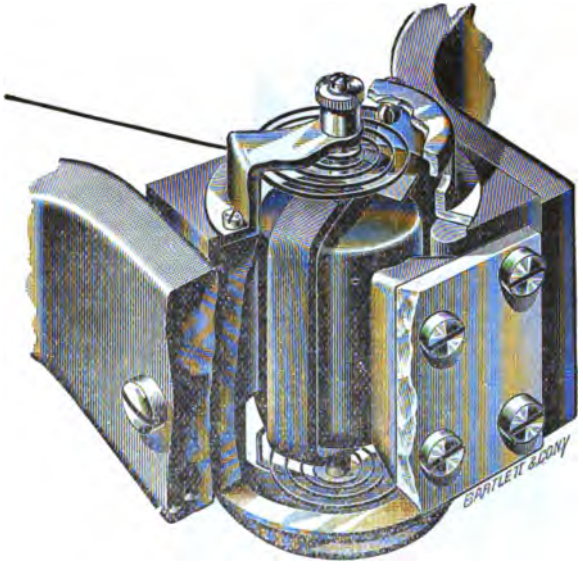


Fig. 26.

COIL AND MAGNETS OF WESTON VOLT-METER (Cover removed.)

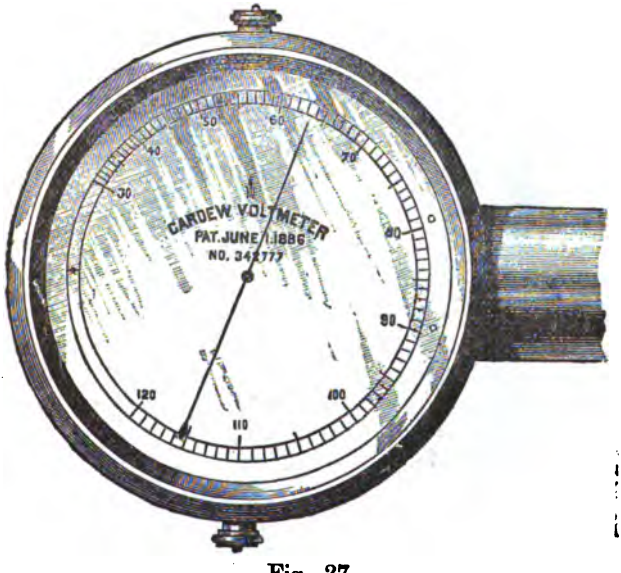


Fig. 27.

CARDEW VOLT-METER.

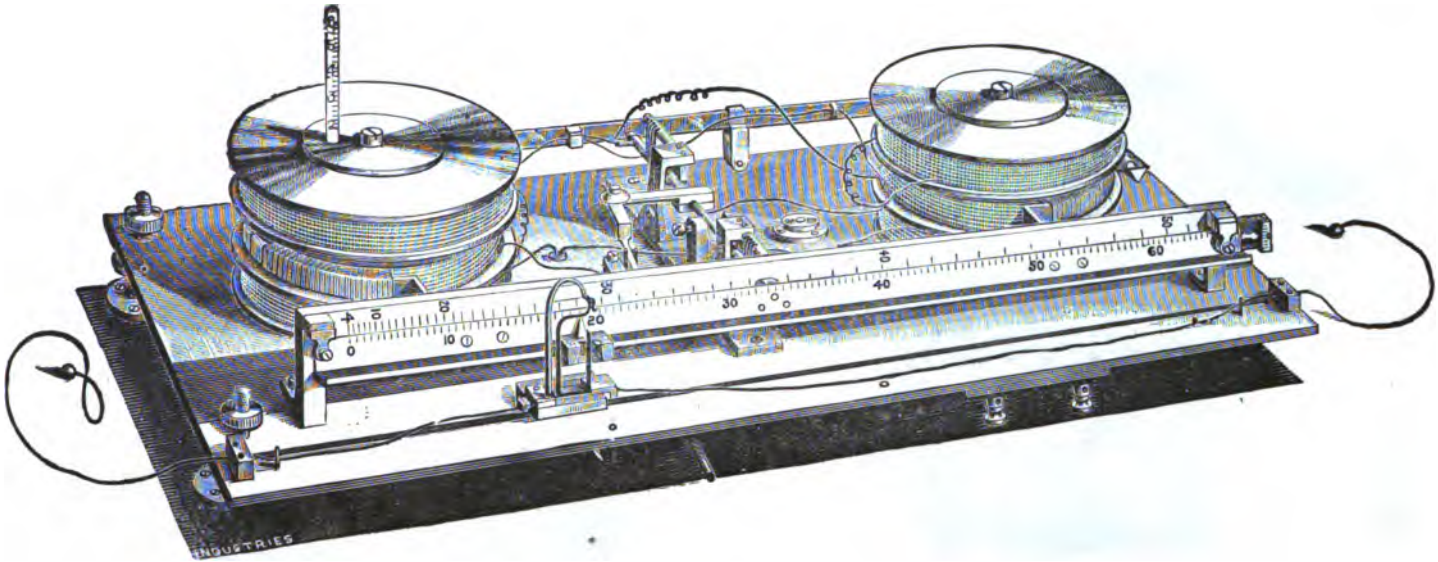


Fig. 28.

SIR WM. THOMSON'S ELECTRICAL BALANCES FOR DIRECT OR ALTERNATING CURRENTS.

The horizontal pattern has the advantage of being steadier than the vertical instrument owing to the disturbance caused by currents of air passing up the tube of the latter. All the more recent forms of this instrument have an adjusting screw outside of the case to bring the needle to zero, which should be done before the current is turned on. No adjustment should be made while the wire remains warm, as the section of the wire may be altered by any tension put upon it while in this condition and the calibration destroyed.

For alternating and direct currents Sir Wm. Thomson's latest in struments are the finest yet produced, but are more suited for standard or station use than as testing instruments. In the electrostatic-instruments no current passes through the instrument at all, and so the conditions of a battery or dynamo on open circuit can be found with perfect accuracy. The electrical balances (Fig. 28) are adapted for both alternating and direct currents. To any body desiring a fine standard laboratory or station set of large range, none are better than these instruments, expensive though they be. All stations for alternating current work should have a Cardew or Thomson voltmeter, a portable Thomson multicellular electrostatic voltmeter for testing pressure in consumer's premises, etc., and a Thomson ampere gauge. For direct current stations Weston or Cardew voltmeters for station work and line testing should be used, and Thomson ampere gauges for current measurement. The Westinghouse ammeter, an excellent instrument closely resembling the Thomson ampere gauge, is shown in Fig. 29, and the Edison ammeter in Fig. 30. For rough approximations the latter is a cheap and fairly accurate instrument.

TRANSMISSION OF POWER.

In his Address at the Annual Meeting, the President touched upon the subject of electrical transmission of power, mentioning the installation at the Chollar Mine, Virginia City, Nevada. There a Brush plant is used, as then stated, placed 1680 feet below the surface of the ground, in a chamber 50′ long by 25′ wide by 12′ high, hewn out of solid porphyry. The small stream of water, which drove the wheels at the surface of the mine,—was carried down through two iron pipes one 10″ and the other 8″ diameter, connected together at the bottom of the shaft by a Y into a single pipe 14″ diameter from which 6″ pipes lead to the Pelton water wheels' nozzles, there developing sufficient energy through the generators to transmit to the surface by well insulated cables 450 H. P. The waste water is conveyed away through the Sutro Tunnel, which pierces the side of the

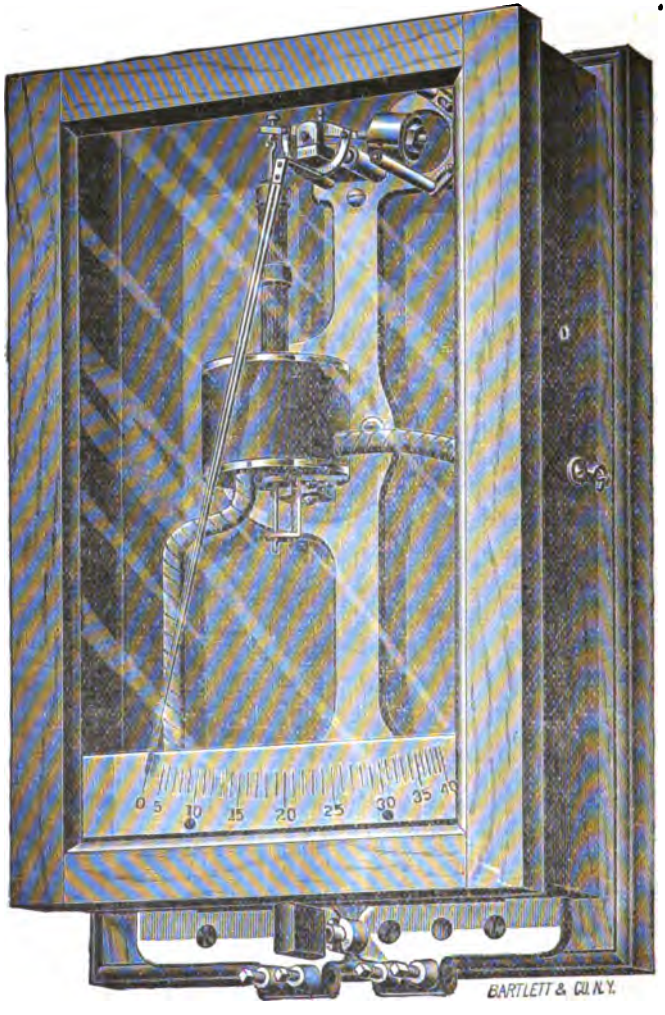


Fig. 29.

WESTINGHOUSE AMMETER.

mountain for the drainage of the mines—in itself a monument of engineering ability and Western enterprise. This is at present the largest installation in the world for transmission of power by stationary electric generators and motors.

About August last a generator and a motor of exactly the same type as those placed in the Chollar Mine were installed at Messrs. Barber & Co.'s Mills, Georgetown, Ont. The water of the Credit river was dammed over two miles below the mill, and a water wheel and shaft were placed in a building there along with the generator. A copper wire was carried back and attached to the motor, which develops 75 H. P. in the mill.

ELECTRIC RAILWAYS.

Four years ago there may be said to have been no electric railways in operation in America. Yet according to the most reliable sources of information there were 636½ miles of electrically equipped railways in operation and 700 miles under construction at the end of December, 1889: 1063 electric cars were then running and 771 cars were being equipped. The total number of completed roads was 107, and 85 were under construction. Of these roads two were running in Canada, their total length being 10 miles, and these were equipped with 10 motor cars. The first, at Windsor, Ont., with two miles of road and two cars, has now been at least four years in operation; the other is at St. Catharines, and the length of road is 8 miles, and it is equipped with 8 cars. Both roads use the Vandepoele system. The road at Victoria, B.C., is now running. The track is 4 miles long, with 6 motor cars. The Vancouver road, which is likewise 4 miles in length, and is to be equipped with 4 motor cars, will be running about the beginning of June. The Thomson-Houston system is used in both cities, and a contract for a short line in Toronto, on which two motor cars will be used, has lately been closed with the Thomson-Houston Company, which has done by far the largest amount of work in Electric railways, the Sprague Co. ranking next. The following table shows the amount of work done by various companies and that under construction in January last.

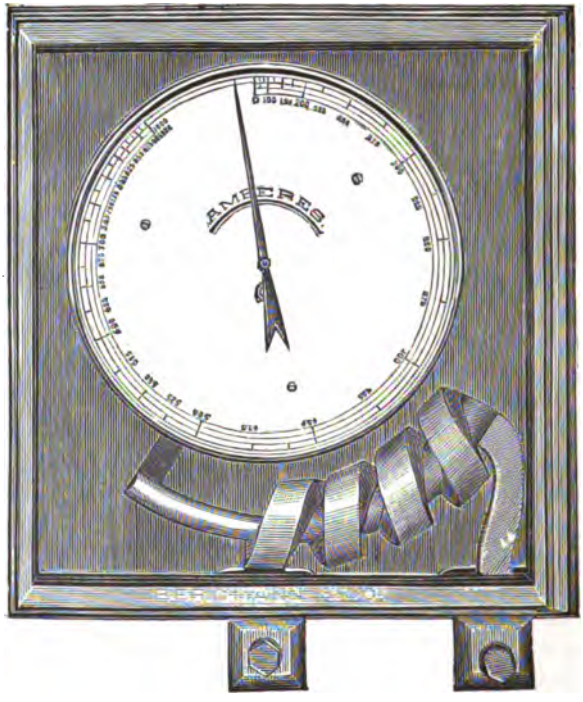


Fig. 30.

EDISON AMMETER.

ELECTRIC RAILWAYS.

In operation and under construction, Jan., 1890.

Name of System.	In operation.		Under construction.	
	No. of Roads.	No. of Cars.	No. of Roads.	No. of Cars.
1 Thomson-Houston	47	490	37	509
2 Sprague	35	408	33	218
3 Daft	10	66	5	15
4 Van de Poele	8	57		
5 Short	3	17	1	5
6 Bentley-Knight	1	6	1	20
7 National Electric Traction Co.	1	1	5	not given
8 Julien	1	10		
9 Fisher	1	4	2	not given
10 Henry	1	4		
11 Rae			1	4

Within the past few months great activity has existed in electric railways in the United States, and the two leading companies in this business have contracted for several hundreds of cars each ; the lead of the Thomson-Houston Company having increased, while the Sprague Company has over 1200 motors cars in operation or in course of construction.

The largest electric street railway system in the world is that of the West End Railway of Boston, contracted for by the Thomson-Houston Company, of which the following particulars may be of interest: At the present time there are 150 cars running, and when completed there will be 600 in operation. Now there are 56 miles of road electrically operated, and 236 are to be equipped. In the power station from 3.30 till 7 p.m. the electrical plant, which is capable of developing, if called upon, 2500 H. P., usually furnishes from 1000 to 1500 H. P. The cars generally in use are 16 ft. closed cars, each carrying 30 passengers, and towing a similarly loaded car. Such a car, equipped with a single 15 H. P. motor, averages in speed 15 miles an hour on the level, and will pass a grade of 5½ per cent. at a rate of nine miles an hour. Such work is, however, rather severe for constant use, and for heavy work they are using two 15 H. P. motors. The potential used is 500 volts, and the average rate of speed is from 10 to 15 miles an hour. The weight of a motor car equipped is 6 tons. The cost of steam power is from one to four cents per car mile, taking 100 miles per car

per day as a basis; the cost of operation and maintenance, four to six cents per car mile on the same basis; the cost of repairs to electrical apparatus is from one and a half to two cents per car mile; cost of management from one to two cents per car mile, and the average total cost of operation is nine and a half to sixteen cents per car mile, according to the number of miles operated.

Unfortunately the severe winters and heavy snow-falls of Montrea and other cities in Eastern Canada preclude the possibility of working electric railways the whole year on our present street roads, but it is a question worthy of the study of members of this Society, whether it would pay to operate our roads electrically during the seven months of open weather which we get, or if a system of overhead railways along our main traffic thoroughfares operated electrically, and which could be run the whole year round, would not be a good investment.

STREET WIRING FOR ELECTRIC LIGHTING.

First, on account of the dangers of break down from heavy sleet storms, and the variation in tension of wire caused by the extremes of temperature experienced in Canada, poles should be placed not more than 135 feet apart, or say 40 to the mile. They should all be good, sound, straight cedar, 7 inches diameter at the top, and not less than 35 feet long, and should be set in the ground to a minimum depth of 6 feet and securely tamped. The cross arms should be of sound timber $4\frac{1}{2}'' \times 3\frac{1}{2}''$, well painted, and fixed in gains cut in the poles and secured thereto by lag screws 8″ long, which would thus enter into the pole about $4\frac{1}{2}$ inches. They should never be attached by spikes only. Wherever telephone or telegraph wires run in the same streets, the poles should be of sufficient height to carry the electric light wires at least four feet above them. Bare wire for carrying either high or low tension currents in towns should be strictly prohibited. The insulation of the wire should be both fire-proof and weather-proof, and of such tough texture as to withstand abrasion should other wires by any means fall across the electric light wires. None but the best double petticoat glass insulators should be used.

For outside construction some of the English Board of Trade Regulations, which might be adopted with advantage in this country, are as follows, the numbers given being those of the Regulations:

1. An aerial conductor in any street shall not in any part thereof be at a less height from the ground than 20 feet, or when it crosses a street, 30 feet, or within six feet of any building for the purposes of supply.

2. Every support of aerial conductors shall be of durable material and properly stayed against forces due to wind pressure, change of direction of the conductors or unequal lengths of span, and the conductors and suspending wires (if any) must be securely attached to insulators fixed to the supports. The factor of safety shall be at least 6, and for all other parts of the structure at least 12, taking the maximum possible wind pressure at 50 lbs. per square foot.

5. Every aerial conductor shall be protected by efficient lighting protectors.

6. Where any conductor crosses a street, the angle between such conductor and the direction of the street at the place of such crossing shall not be less than 60 degrees, and the spans shall be as short as possible.

7. Where any aerial conductor is erected so as to cross any other aerial conductor, or any suspended wire used, for purposes other than the supply of energy, precautions shall be taken by the owners of such crossing conductors against the possibility of that conductor coming into contact with the other conductors or wire, or of such other conductor or wire coming into contact with such crossing conductor by breakage or otherwise.

11. The insulation resistance of any circuit using high pressure aerial conductors, including all devices for producing, consuming or measuring energy connected to such circuit, shall be such that should any part of the circuit be put to earth the leakage current shall not exceed $\frac{1}{5\,5}$ of an ampere in the case of alternating currents. Every such circuit containing high pressure conductors shall be fitted with an indicating device which shall continuously indicate if the insulation resistance of either conductor fall below the conditions required by this regulation.

"14. The owner of every aerial conductor shall be responsible for the efficiency of every support to which such conductor is attached.

"15. Every aerial conductor, including its supports, and all the structural parts and electrical appliances and devices belonging to or connected with such conductors, shall be duly and efficiently supervised and maintained by and on behalf of the owners as regards both electrical and mechanical condition.

"16. An aerial conductor shall not be permitted to remain erected after it has ceased to be used for the supply of energy unless the owners of such conductor intend, within a reasonable time, again to take it into use.

"17. Every aerial conductor shall be placed and used with due regard to electric lines and works from time to time used or intended to be used, for the purpose of telegraphic communication, or the currents in such electric lines and works, and every reasonable means shall be employed in the placing and use of aerial conductors to prevent injurious affection, whether by induction or otherwise, to any such electric lines or works, or the currents therein."

The author considers that rules 7, 13, 14, 15, 16 and 17 should be equally binding upon telegraph and telephone companies whose wires are often as carelessly constructed as those of any electric light company, and have in consequence been quite as blameworthy for fires originating from electric currents.

HOUSE WIRING.

In the interior wiring, none but high class rubber-insulated wire protected by an outer linen tape or other efficient covering should be used.

None but porcelain or slate base cutouts and switches should be allowed, and the sweating of drop wires for single lights on the main wires (such wires being afterwards twisted together and brought down to the lamp socket) should be prohibited.

Wherever lights are suspended by wires, stranded conductors, equal in area to No. 20 standard wire gauge, covered with a good solid rubber coating and protected on the outside by silk or cotton braiding, should be used, and where taken off from the main wires a porcelain rosette cut-out, such as the K. W. rosette, should in all cases be provided, or a wood base rosette may be used, provided it is rendered fireproof.

No switches should be used which do not break contact quickly and automatically, or in which spring copper makes a connection; such copper is heated by the passage of a large current, and by losing its hardness therefrom often fails to make good connection, and so may cause an arc to form. The Paiste switch is the only one at present made on this continent in which these objections are successfully met.

Fuses for cut-outs should not be interchangeable with others of widely different capacity. Over-loading of wires first designed for lighter loads would then be impossible.

The joints in wires are preferably made with connectors such as the MacIntyre wire joint, as soldered joints on which acid has been used frequently corrode through the excess of acid not having been removed on completion of the soldering, and it has been the author's experience that ordinarily wiremen will not take the time or trouble to make a good joint with rosin as a flux.

It must be remembered that a low tension continuous current is more liable to cause a fire in case of short circuit between the main wires than an alternating current, owing to the connection which exists directly between the dynamo and the house wires, permitting the entrance into the house of an enormous current, while with the alternating current system the short circuiting of the secondary house wires will only result in the immediate melting of the fine wire fuse in the primary circuit of the converter. There should be no relaxation, therefore, of adopted regulations in favour of low tension direct systems on account of supposed greater safety, a thing which does not exist in their case, but both direct and alternating current systems should be treated alike so far as the wiring of consumers' premises is concerned, and the present standard should be raised, not lowered.

It should not be forgotten, that one of the most important elements in the attainment of perfect safety to everybody concerned is the employment by supply companies of properly qualified and experienced labour both for the construction and for the running of plants. It will be found to be very poor economy to employ bell-hangers, plumbers and even shoemakers on work requiring considerable electrical and mechanical knowledge and clear judgment, as is done at the present time in some Canadian stations which might be mentioned, merely for the sake of saving two or three hundred dollars a year in wages, a sum which is much more than counterbalanced by the unsatisfactory results in the lighting and the additional cost of repairs. Nor should it be forgotten that a cheap and poorly constructed electric lighting plant is the worst of all possible investments.

To reassure the timid whose nerves have been so skilfully played upon by advocates of low tension systems, the following opinions of Sir William Thomsom, Dr. John Hopkinson, Mr. W. H. Preece, Professor George Forbes and Monsieur E. Fesquet, handed in at a recent meeting of the New-York Senate Committee on Electric Lighting, may be cited. These gentlemen, whose qualifications to speak authoritatively on the subject cannot be questioned, are practically unanimous in the opinion that the distribution by alternating currents can be and is safely carried out by underground or overhead wires at pressures of 2000 to 2500 volts; that absolute safety to the person can be and is obtained in the use of such currents; that there is less danger from fire from an alternating current system using converters than from a continuous low tension current connected direct from the dynamo to the consumers' premises (and the higher the tension in the primary the greater the safety in this respect); that on account of

the small current and the consequently smaller area of copper wire required for its distribution, the alternating current has many advantages over all systems of low tension distribution; and that a properly constructed and mounted converter is in itself an effective protector to the user of electric illumination against danger from shock or fire.

In conclusion the opinion may be hazarded that within the next ten years three-fourths of the incandescent electric lighting on this continent, following the example now set in Europe, will be carried out on the alternating current transformer system at increased rather than lower pressures than at present used, and that a large proportion of our mills and factories situated within five or even ten miles of water powers will be run by electric motors either driven direct by high tension continuous currents or by low tension alternating currents obtained through converters attached to primary conductors carrying a high tension and small current.

The thanks of the author are due to the Westinghouse Electric Co. of Pittsburg, the Brush Electric Co. of Cleveland, the Thomsom-Houston International Electric Company of Boston, the Royal Electric Co. of Montreal, the Ball Electric Light Co. of Toronto, the Reliance Electric Light Co. of Waterford, Mr. J. J. Wright of the Toronto Electric Light Co., Messrs. J. W. Queen & Co. of Philadelphia, the Weston Electrical Instrument Co., of Newark, N.J., and to Mr. A. Barthmann of New York, representing Mr. W. Hackenthal of Berlin, for particulars of machine and instrument construction and loan of woodcuts. His thanks are also specially due to Mr. T. Commerford Martin, Editor of the "ELECTRICAL ENGINEER," New York, for statistics concerning the electrical industries of the United States, and to Mr. F. R. Redpath of Montreal for the photographs of the electric light plant in his residence from which the engravings thereof have been produced.

DISCUSSION.

Mr. D. A. Starr said the author had given correct information as to the weight and output, etc., of the Thomson-Houston incandescent dynamo, but had made a mistake in stating that the machine was not absolutely automatic. The author had referred also to the manner in which the series coils were wound, the winding being over the armature and not around the fields. This was an invention of Professor Elihu Thomson's, whose brother, Mr. F. Thomson, chief electrician of the Royal Electric Co., being present, would, he thought, be able to explain exactly how the automatic arrangement worked. Mr. Starr.

Mr. Thomson and he had recently tested, for delicate regulation, a machine of the kind under discussion, and the difference between full load and no load in cutting off the whole of the lights, on a 150 light machine, was nothing; it could not be seen on the lamp that the current had increased by cutting off the whole of the lights.

A volt meter was put in the circuit, and it was found that when the lamps, with the exception of one, were cut off the machine (150 light) the pressure dropped 5 volts out of the 110 (5 per cent.). The machine could be made to compensate either way by changing the series coils.

The advantage was that in wiring for a building that was to be wired for 5 per cent. loss with the full number of lamps burning on the circuit, if a number of lights were cut off the actual loss was nothing. The result, if there were no drop in gauge, would be that the lamps would brighten up that 5 per cent.; but instead, if there was a drop, it compensated for the loss in the wire, and the lamps were kept at their normal brightness all the time.

The speaker said he mentioned this machine because he knew it well, its perfect automatic regulation, and also that any loss could be made up and compensated for. He did not think Mr. Lawson had seen one of these machines running under the same circumstances, or he would be willing to alter his opinion and classify the machine in his paper as being absolutely automatic.

Mr. F. Thomson, referring to the Thomson incandescent dynamo, said that the reason the coils were placed on the machine in that peculiar manner was to make it perfectly automatic and to produce a neutral point, so that there would be no shifting of the brushes necessary when the load was charged. Mr. Thomson.

The machine could be made to increase or decrease, or to remain automatic without loss, according to the position of the series coil and the strength of the shunt.

When the machine was first constructed for 800 lights, some little shifting of the brushes was necessary on account of the wire taking effect on the fields in the front, the wire being so long; but this is now corrected.

According to Mr. Lawson's remarks on the Brush machine, the exciting current was 22 amperes and 135 volts, equal to 2970 watts for 1000 lights. In the Thomson machine, manufactured by the Royal Electric Company of Montreal, the exciting current was 30 amperes and 90 volts, which would be 2160 watts for 1200 lights. In the Westinghouse machine for 1500 lights the exciting current was 14 amperes 110 volts, equal to 1540 watts.

There must be something wrong in this. By referring to the exciting current of the Brush and Thomson machines it will be seen that the Westinghouse requires just about half the watts; in the Westinghouse machine the current passes through one coil on the field, then misses a coil, and again passes through a third coil, misses a fourth; and then through the fifth, etc. In consequence, there are practically two branches of current, the second branch passing through the second, fourth, sixth, etc., so that the 1500 light machine has 12 fields, six in series and two in multiple, 14 amperes passing through six, and 14 amperes passing through the other six, making in all 28 amperes and 110 volts, equal to 3080 watts.

A machine described in Dredge on Electric Illumination, Vol. I., page 250, and invented by a Mr. Lachaussie of Liege, will be found to resemble the Brush alternating machine of to-day in almost every point. With regard to taking out a section of the armature while the Brush machine was running, the same thing could be done with the Lachaussie machine.

With reference to the Fort Wayne meter, he believed Mr. Edison had some very early patents on motor meters, and that these patents would include the above mentioned meter because they covered broadly all motor meters.

He was sorry the author had not compared transformers of the same size, as it was difficult to arrive at a conclusion when comparing various sizes.

Referring to the low tension dynamo: of course a machine that was perfectly automatic should keep the same voltage at any speed; he did not claim that the Thomson machine would do that, but it would give

any desired voltage required by changing the shunt and position of the series coils, so that if a place was shunt wired for a 10 per cent. loss, it could be made up at the dynamo, or any other loss could be made up in the same way. The series coils could be placed in a certain position and the machine would be perfectly automatic, or it could be made to drop its voltage when the lights were switched off up to 25 per cent. The series coils take direct action on the armature. He would like to see the paper correct; at present it was not.

He admitted the diameter of armature was a little too great in relation to length in some of the early large machines.

In these the armature should have been longer, but this has been rectified now. In machines of 100 to 500 lights the series coils would hold the neutral points in the centre. It was possible by moving the series coil back, if the lights were increased on the machine, to move the brushes farther back, not ahead. The series coils being placed over the armature, they took direct effect on the armature independent of the fields.

Mr. A. J. Lawson, replying to Mr. Kimball, said that the Brush alternating current system at Barrie had been in operation since January last. There had been no accidents there on account of the high voltage. The only accident had been the burning out of an armature coil one night before the station work was completed, on the fuses being put on the main wires, through an arc wire light coming in contact and crossing both wires out-going and return, and this would have occurred with any low tension machine. Mr. Lawson.

The Edison people had practically given up the use of equalizers in central stations, and were instead interlacing the feeders. Some stations lately constructed had them in use, but the present rule of the Engineering Department was to interlace the feeders at all points, especially the neutral wires. There was a Westinghouse arc light plant in operation in Boston in the City and Suburban Company's station, and there was another in the United States illuminating station in New York running about 125 lights. He had been informed there were about 10 or 12 plants installed since the one in Boston had commenced running.

Referring to Mr. Thomson's remarks about the Thomson machine, he would simply say that if the absolute perfection of regulation claimed had really been attained, there was a fortune in it both to Mr. Thomson and his Company, for many had been striving to attain perfect regulation hitherto without perfect success.

The over-compounding of five volts he thought excessive, as there was very little lighting done by isolated plants, which was not done between 4.30 and 6 p.m. in winter, and 5 per cent. loss he thought in that case was simply a waste of coal.

He did not make any special reflection on the Thomson machine in stating that it was not perfectly automatic, but simply stated what he believed to be the case, viz., that the machine was not perfectly automatic in regulation.

The paper was not confined to a description of the construction of dynamos, and he had not therefore gone into details of the reasons for winding in any particular way.

With regard to the Westinghouse machine, the particulars given had been obtained from the superintendent of the Westinghouse Electric Co., and he had found the figures given to be correct.

In describing the Brush machine as a departure from the ordinary types of machines constructed in America, he had said only what was correct. To call the Brush alternating current dynamo an old form of machine was wide of the mark. One might, with more reason, call the Thomson-Houston alternating machine simply a Westinghouse alternator, because the construction was practically the same. Another thing, there was no iron, and, therefore, entire absence of treating effect due to iron in the armature of the Brush alternating machines.

He had given the Thomson machine credit for being better regulating than the Edison, but he could not see that any machine was yet perfect; and as regards the construction of the machine, there were reasons occurring to him why there should be a waste of magnetism in the machine with the stationary coils in any position. Taking the larger machine, a change of brushes was necessary. In some of the later English machines, without placing the coils in such a manner as Mr. Thomson did, by particular attention to the relative dimensions of the armature and of the field, the position of the brushes did not require to be altered under large changes in load.

In the construction of the armature of the Thomson-Houston machine he thought Mr. Thomson would admit that the diameter of his armature was too great in relation to its length, especially in some of the larger machines.

In such construction there was a quantity of dead wire at the ends. With the same diameter and greater length the output could be increased while the speed would be somewhat lower.

Thursday, 22nd May.

J. KENNEDY, Vice-President, in the Chair.

The following candidates having been balloted for were declared duly elected as:—

MEMBERS.

OCTAVE CHANUTE, JOHN WILLIAMS.

ASSOCIATE MEMBER.

WALTER CONSTANTINE BROUGH,

ASSOCIATE.

LEONCE FRANCOIS LUDOVIC STEIN,

STUDENTS.

OSCAR ARCAND,
THOMAS ROSS DEACON,
JAMES ATKINSON DOUGLAS,
ANDREW LANE,
BARTLETT MCLENNAN,
THOMAS MCLEOD,
JOHN RANKIN, JUN.,
ARNOLD J. RYAN.

The following has been transferred from the Class of Associate Members to that of Members :—

REUBEN WELLS LEONARD.

The discussion of Mr. A. J. LAWSON's paper on the "Generation, Distribution and Measurement of Electricity for Light and Power, etc.," occupied the evening.

ERRATA.

Vol. IV.

Page	17,	Line	35, *for*	" citizens deserve "	*read* " company deserves."
"	25,	"	34, "	" 2 "	" " 3."
"	171,	"	31, "	" wire "	" " were."
"	267,	"	16, "	" I and II "	" " VIII and IX."
"	269,	"	40, "	" I "	" " VIII."
"	271,	"	15, "	" I and II "	" " VIII and IX."
"	271,	"	25, "	" I "	" " VIII."
"	272,	"	39, "	" II "	" " IX."

INSTRUCTIONS FOR PREPARING PAPERS, ETC.

In writing papers, or discussions on papers, the use of the first person should be avoided. They should be legibly written on foolscap paper, on one side only, leaving a margin on the left side.

Illustrations, when necessary, should be drawn on tracing paper to as small a scale as is consistent with distinctness. They should not be more than 10 inches in height, but *in no case* should any one figure exceed this height. Black ink only should be used, and all lines, lettering, etc., must be clear and distinct.

When necessary to illustrate a paper for reading, diagrams must be furnished. These must be bold, distinct and clearly visible in detail for a distance of thirty feet.

Papers which have been read before other Societies, or have been published, cannot be read at meetings of the Society.

All communications must be forwarded to the Secretary of the Society, from whom any further information may be obtained.

The attention of Members is called to By-laws 39 and 40.

Thursday, 9th October.

P. A. PETERSON, Member of Council, in the Chair.

Paper No. 44.

DEVELOPMENTS IN TELEGRAPHY:

WAY-WIRES MULTIPLEXED AND INTERCHANGEABLE.

By D. H. KEELEY, A. M. CAN. SOC. C.E.

The title of this paper is so comprehensive that it might be supposed the writer purposed giving a *résumé* of all that has been attempted in the way of signalling since the word *telegraph* was first coined and found place in our vocabulary. It may be well therefore to state at the outset that it is only intended to deal with the subject of telegraphy in its present stage, introducing just enough of retrospect to show the drift, so far, of successful research in lines that, if followed up, will carry us to the realization of perfection in the art; and that is nothing short of the complete utilization, with the utmost economy, of the capacity of a line wire for the transmission of electrical effects.

Telegraph apparatus, and systems of telegraphy, have been so rapidly multiplied that scores of volumes and text-books are extant devoted exclusively to their treatment, either specifically or generally, and the student in wading through them finds difficulty in reconciling the idea of advancement with the circumstance that, whereas indisputable and important properties of conductivity and electro-magnetism were early discovered, the inventions from time to time introduced, instead of aiming to more and more fully utilize these properties, appear to have been designed to do in different ways just what had already been accomplished in the absence of a clear recognition of the possibilities attainable.

Supposing, however, for the sake of convenience, that two well-established facts—the *celerity of conductivity*, and the *diverse properties of electro-magnetism*—were ever held in mind by the workers in this field, it will be possible to discriminate between the different systems that have been brought forward.

There are those, in that case, that have been designed to utilize the capacity of a line wire for the rapid transmission of electrical effects; they may be comprehensively designated *Simple Circuit Systems*. And there are those that have been designed to utilize the diverse properties of electro-magnetism, in which the use of auxiliary circuits is necessary; they may be described as *Complex Circuit Systems*.

With this division in mind, it will occur to those conversant with the subject, that whatever *progress* has so far been made in the field of telegraphy is referable to the Complex Circuit Systems, comprehending the various methods for duplex and quadruplex transmission; while the obviously more far-reaching province of the Simple Circuit, which embraces several automatic and synchronous systems, has been comparatively neglected, and, although extensively experimented in with splendid success, has never been developed in a measure to surpass the performance of its original arrangement constituting the ordinary Morse telegraph of forty years ago.

As this unique system, the Morse, is still universally in use, and a great deal depends upon its existence, it will be profitable to review it before proceeding further, for anything so old in the history of an art as this system is in telegraphy must have some remarkable features to recommend it.

Like the proverbial law that "holds good," the Morse has *nine points* that defies its dispossession of the field:—

1. The transmitter is a single contact key. The limit to speed is the physical possibility of an operator's manipulation, and the matter to be transmitted needs no special preparation.

2. The receiving instrument is simply an electro-magnet, the armature of which directly reproduces the movements of the transmitting key; and the immediate transcription of the operator is in proper shape for delivery.

3. The receiving instrument being electro-mechanical, an automatic repetition of transmitted signals from one circuit to another is readily obtained.

4. The circuit current is supplied from batteries at one or *both* of the terminal offices.

5. There may be any number of offices on a single wire, the only limit being the accommodation for traffic; and any number of the intermediate or way offices may be in or out of circuit without affecting the operation of the others.

6. The way offices are not called upon to contribute battery current to the main circuit.

7. The wire can be earthed at any point, thereby forming two separate circuits from earth to the respective terminal offices; each circuit being operative for all of the offices included in it.

8. At any way office, one wire can be switched to connect with another, the equipment of the lines being uniform.

9. The last and very important feature is, that in the act of transmission, substitution of messages or interruptions by the receiving operator, or by any other in the circuit, can be effected instantly.

These are the *nine points* of advantage that distinguish the slow old Morse, and these are the advantages that render it as yet pre-eminent and indispensable.

There is no other system possessing all of these features, consequently there is none other equally advantageous. And it is clear that if the usefulness of a wire is to be enhanced, its equipment should have in its composition the means for affording, in each separate line of communication, the facilities of the single Morse circuit.

It is found, however, on examination, that this great desideratum has not been secured in any of the various methods that have heretofore been invented for the purpose of increasing the practical utility of the wire. [*It is important to bear this circumstance in mind in following this paper to its conclusion.*]

In reviewing the field of telegraphy it will be convenient to consider first the

SIMPLE CIRCUIT SYSTEMS.

From time to time, dating from an early period in the history of our telegraphs, attempts have been made with more or less success to transmit signals by means of automatic *make* and *break* devices, perforated strips and the like, and to effect their reproduction by the action of the current impulses upon moving strips of chemically prepared paper. The speed attained has not unfrequently been marvellous and fairly incredible.

Without entering into a discussion of what may or may not have been the conditions of the circuits at times so successfully operated, it will suffice to state that the performance of these systems was not uniformly good and reliable.

Theoretically, any one of these systems would utilize the signalling capacity of a wire to its fullest extent. An almost inconceivably rapid succession of *makes* and *breaks* at the transmitting end of the line will produce a corresponding number of dots or dashes on the recording strip at the receiving end. And, since the current can effect chemical decomposition in a very much shorter time than it can produce the

manifestation of magnetism, it is obvious that the same speed could not be attained by any arrangement of electro-magnets.

This will be understood in view of the fact that a telegraph line 300 miles long is capable of transmitting about 1125 distinct electro-chemical effects per second. By an *effect* is meant the manifestation at the receiving end of the application or the withdrawal of current at the sending end. In a Morse operator's fastest manipulation (40 words per minute), there are produced but 24 electro-magnetic effects, or an equivalent of 12 dot signals per second.

At first sight, then, it would appear that an automatic system of the kind described, made reliable, would fill every requirement, and afford us in a single circuit the accommodation for which we are accustomed to employ a score or more of wires. Such is not the case in practice, however, and it is the discovery of its innate shortcomings and comparative inutility that has caused attention to drift away from the electro-chemical circuit.

The characteristic and maybe inseparable conditions most palpably disadvantageous to all of the automatic systems are that:

The matter to be telegraphed must be translated or specially prepared for transmission, and on its reception has to be retranslated for delivery. The collective preparation of a large amount of matter precludes the practicability of giving precedence to any single despatch on occasion. The signalling current emanates from the sending end alone; consequently the corresponding offices must take turn about in transmitting, and there is no accommodation for way offices unless equipped as terminal stations, which they are in fact constituted when in operation.

Besides these drawbacks to the automatic systems, there is the unavoidable nuisance of the paper tapes used at both the transmitting and receiving ends of the line. When the Morse system was developed to that stage where the single tape at the receiving end was dispensed with, a sigh of relief went up from every quarter where the business was of sufficient volume to produce an accumulation of the stuff in the course of a few hours work. The automatic in this respect is a retrograde system; in its working the paper tapes form the most important feature; the perforated and the marked material rapidly accumulates, and if fyled for purposes of reference it is difficult to get at any particular despatch, and no part of one can be so readily recognized as the easily fyled manuscript of despatches sent or received by the Morse system.

In fine, it has been found that the automatic systems cannot be

advantageously operated, and the extreme rapidity of the chemical apparatus is, therefore, rendered practically unavailable.

The nearest approach that has been made to a realization of the expectations reasonably entertained of the electro-chemical systems is the performance of the Wheatstone Automatic. This system is a sort of compromise between the electro-chemical and the ordinary Morse. Its transmitter is essentially the same as those employed in the other automatic systems, while its receiver is electro-magnetic. The speed attained is of course much lower than that of the chemical apparatus, yet it is remarkably high compared with the work of a directly manipulated Morse circuit. It has already been stated, that in the operation of an electro-chemical system, 1125 effects can be produced per second, and of the Morse system, 24; with the Wheatstone system the rate attainable is as high as 386 electro-magnetic effects per second. In common with the other automatic systems, however, it has the already defined drawbacks rendering its general application impracticable.

Several printing systems have been brought forward but have not scored any great success. The chief defect in these is that the signalling medium is necessarily idle during the time that the mechanism operates to present successively the characters called for by the transmitter. With these therefore only a part of the signalling capacity of the wire is utilized, and a very high speed is obviously unattainable.

Another phase of simple circuit operation is presented in the systems that have been devised to transfer the line wire from one apparatus to another successively at both ends of the circuit, and thus afford for each corresponding set an intermittent connection so rapidly recurring as to constitute a practically continuous one.

For a long time after the idea of these systems was suggested, it was considered impracticable, in consequence of the difficulty of obtaining the requisite perfect and continuous synchronous action of the machinery at either end of the line. In 1883, however, that difficulty was got over by the adaptation, in Mr. Delaney's synchronous multiplex, of the *phonic wheel*, a species of electro-motor; and more recently Lieut. Patten has succeeded in adapting an alternate current motor for the same purpose. (See the *Electrical World*, Vol. XIII, p. 106.)

Delaney's multiplex comprises the best features of all of the synchronous systems that preceded it. He has succeeded in getting with it six circuits suitable for the fastest Morse transmission. It is in operation on some lines in England and in the United States. The utility of this system, however, is limited in consequence of some very serious defects that will be specifically dealt with later on.

We now come to a consideration of the

COMPLEX CIRCUIT SYSTEMS.

The possibility of simultaneous transmission in opposite directions through a single wire was an early conception, but it was not until 1872 that the idea found practical application.

As soon as the principle became generally known and understood, the *Duplex*, as it is called, was introduced in multifarious forms. Its principle is a prolifically suggestive one, and in one form or other it is now found in operation wherever the traffic between any two stations is of considerable volume.

Of all the systems for duplex telegraphy that are in existence, however, there is but one—a somewhat recently introduced combination of telegraphic and telephonic apparatus—practically applicable to way stations. The reason for this is that the duplex depends for its operation upon devices for neutralizing the effect of outgoing currents in the receiving instruments, while leaving the latter free to respond to incoming currents. This necessitates the placing of main line batteries at each transmitting station, an arrangement that is, as already explained, impracticable for way offices, especially on lines of any considerable length.

The *Quadruplex*—an arrangement of apparatus for double transmission in opposite directions—first appeared in practicable shape in 1874. It is essentially an adaptation of the duplex principle ; a combination, as it were, of two duplexes. There are, however, only four forms of the duplex susceptible of being so adapted. These are the Differential, Bridge, Split-battery, and Reciprocal (the last mentioned is described in the U. S. patent No. 331,975 granted to the writer conjointly with Mr. Aaron Garvey in 1885). For the exchange of business between centres where the wires are constantly occupied, the quadruplex, in one or other of its forms, is now extensively used all the world over.

The general features of the quadruplex may be stated to consist in means for neutralizing the effect of the outgoing currents in the receiving instruments, and for effecting the production of signals on one side by increase and decrease of current, and on the other side by reversals of this current; or, as in the Reciprocal system, by currents of a given strength on the one side and heavier currents of the same polarity on the other side.

Attempts have frequently been made to apply these means for the production of a *Sextuplex* system; but the greater necessity for special devices such as are used in the quadruplex to obviate interference of the effects of the current of one side with the other, involves so great

an amount of complication and machinery as to render the idea impracticable.

The inherent defects of the several quadruplex systems consist in:—

1. The receiving instrument is in every instance dependent for its energization upon the battery at the transmitting station. This necessitates nice adjustment on the one hand and extraordinarily heavy currents on the other.

The fine adjustment of the receiving instrument exposes it to the influence of induction from strong currents transmitted from the same end in wires running parallel to its circuit. And the heavy currents transmitted to effect the receiving instruments occasion the same mischievous induction effects in other circuits adjacent.

Owing to these conditions it is a matter of considerable difficulty to keep the apparatus in working order.

2. There is no means for including intermediate offices in circuit.

3. One receiving operator is unable to interrupt his correspondent without interrupting the other two operating on the same side. That is what occurs in each of the duplexes; each of which has four operators,—a sender and a receiver at each end. Hence, of 4 or 8 operators at work on one wire, three are handicapped if the fourth be inexpert; and it has thus become necessary to detail the best available operators for duty on duplex and quadruplex circuits.

With these facts before us we can readily understand the fairness of its being estimated, that the value of a duplex *circuit* is about 90 per cent., and a quadruplex circuit about 75 per cent., that of a simple Morse line between any two stations. In other words, a quadruplex is only about as good as three straight Morse circuits. And we can see, too, in the light of these facts, how very far these multiple circuit systems have fallen short of the advantages of the simple Morse circuit set forth in the beginning of this paper. At the same time, it will be remarked that the work done in respect of these systems has been one of steady development and extensive application in practice; they have been brought to that stage where all but their inherent defects are eliminated, and we perceive, in view of the already mentioned signalling capacity of a line wire, that the principles underlying them are not the correct ones on which an *ideal* system can be based.

THE SYSTEMS COMPARED.

To get at a clear idea now of the comparative value of the different systems, we can admit a *maximum* of efficiency in each case—crediting the quadruplex, for example, with the full value of 4 Morse circuits —and set down the highest rates of transmission quoted in works in

which they are specifically treated. By classifying them as hereunto we can readily perceive how they stand.

Single Circuit—*Manipulated.*	*Rate Per Minute.*
Morse	40 words.
Type Writing (Hughes or Phelps)	50 "
Synchronous Multiplex (6 circuits × 40 =)	240 "
Single Circuit—*Automatic.*	
Electro-Chemical	1500 "
Electro-Magnetic (Wheatstone)	428 "
Complex Circuit—*Manipulated.*	
Duplex (2 × 40 =)	80 "
Quadruplex. (4 × 40 =)	160 "

Leaving aside the question of the practical availability of the electro-chemical method, we have seen that the value of its remarkably high speed is reduced by the necessity for dual translation of the matter transmitted; the same is true of the Wheatstone Automatic, the next highest in point of signalling capacity.

Of the systems operated by direct manipulation, the simple Morse is the only one of general utility. The others are, as has been pointed out, only adaptable to terminal stations; of these latter, however, the synchronous multiplex is shown to have the greatest efficiency. It is besides a simple circuit system, and the nearest of any akin to the simple Morse.

The indications are therefore very clearly defined, that the principle upon which the synchronous multiplex is based is the correct one to follow up, with a view to the full utilization of the line wire.

We can now with advantage revert to a consideration of that principle, and in due course it will transpire how, by properly applying it, we can create a perfect system of

MULTIPLE CIRCUITS.

If a moment's consideration is given to the fact, that the signals transmitted by an operator on a Morse wire are made up of dots, dashes, and spaces, it will be perceived that there are in these several conditions certain periods of rest. When the key is open (spacing for instance), the circuit is fulfilling no function. Can this period be taken advantage of, and the line wire for the time of its duration, however short, be transferred to complete a circuit with other sets of apparatus?

That is the question on which the operation of the synchronous multiplex hinged, and it has been answered affirmatively.

To get at an understanding of it, the action of the current upon the electro-magnet must be considered.

It is evident the magnetism developed in the iron core by the action of the current does not appear and disappear in its greatest strength abruptly; there must be a rise and a fall to it. Some time is taken for the magnetism to develop after the current is applied, and some time is taken for the magnetism to die away after the current is withdrawn. There is as it were a residual magnetism in the core for a brief period after the current is withdrawn. And it further appears that the stronger the current is the longer will the residual magnetism last. If the armature of the electro-magnet were arranged to respond to the effect of a weak current, and a strong current were applied, it is evident the armature would remain attracted for some time after the current was withdrawn. If the current were withheld for a brief space the armature would fall away; but if the current were re-applied very quickly, the electro-magnet would become re-energized before the armature would have had time to fall away. Hence, by alternately applying and withdrawing the current very rapidly, the electro-magnet would appear to be influenced by a continuous instead of an intermittent current.

Now, that being the case, it is evident that a number of points in a circle might be made the terminals of conductors leading to the electro-magnet, and a revolving arm successively touching these points might be the means of communicating the current to it. In that case it would only be necessary to apply the current to the arm in order to actuate the electro-magnet. And if between these several points another set of points is placed and put in connection with a second electro-magnet, this one would be actuated in like manner to the first, and so on, until the entire space of the circle were occupied and a considerable number of instruments could be actuated.

Now, if a similar arrangement of electro-magnets and contact points is placed at a distant station, and the revolving arms are synchronized and connected together by a line wire reaching from one to the other, the line wire becomes a practically permanent conductor common to all of the electro-magnets, and yet it is only in connection with the several pairs of them one at a time, so that signals might be exchanged between any two corresponding sets without any reference whatever to the others.

Whether this could be realized in practice, was what Mr. Delaney and others before him sought to ascertain in the working of their respective systems. We have seen the outcome of it in the synchronous multiplex, and the result is very satisfactory. It is, however, not nearly so efficient as it was expected to prove.

In the *Electrical World*, Vol. II., No. 18, of Dec. 29, 1883, and Vol. VI., No. 20, of 14th Nov., 1885, will be found illustrated articles fully

explanatory of the original system and its improvements. These articles can be consulted for details; it answers our present purpose to have gleaned the following facts:—

1. The receiving instruments are actuated by currents emanating from the sending end alone. Hence the system is only applicable to terminal stations.

2. It is necessary to afford to each operator 34 contacts per second with the line wire, in order to enable him to transmit with the same facility as on an ordinary circuit. This is practically equivalent to 3 contacts, or 3 impulses of current per dot signal.

3. The operation is confined to lines not exceeding 100 miles in length.

With these facts before us we perceive that the synchronous multiplex, according to Mr. Delaney's invention, is deficient in two important respects; its application is limited, and it does not economically utilize the signalling capacity of the line wire.

We have not to go very far to ascertain the causes that produce these restrictions.

In several of the text-books the laws governing the transmission of currents are fully set forth. Take for instance the work of Geo. B. Prescott, 1885, Vol. I, wherein it is shown (*see note page* 260) that the time required to actuate an electro-magnet is about directly proportional to the length of the conductor and inversely proportional to its conductivity. An actual experiment is cited, p. 395, whereby it was ascertained that on a No. 8 iron wire 300 miles long, a Hughes (polarized) electro-magnet was actuated in ·003 = $\frac{1}{333}$ of a second; while for an unpolarized electro-magnet the time required is stated to be ·01 = $\frac{1}{100}$ of a second.

By calculation in accordance with these premises, it appears a length of 100 miles of No. 6 iron wire (the size generally used for multiple circuit lines) is capable of producing a signal in ·0022 = $\frac{1}{454}$ of a second on a receiver, † such as is used in the Delaney system. Here are the figures:—

	No. 8		No. 6			
Lengths	300	:	100	}	:: ·01	: ·0022 = $\frac{1}{454}$
Resistances	12·92	:	8·54	}		

† As the Hughes' apparatus already mentioned is not adaptable for general signalling purposes, and the polarized instruments in use, such as the Siemens relay, have practically about the same celerity of action as an unpolarized electro-magnet, the time required to produce a signal on an unpolarized magnet on the 300 mile line, viz., ·01 sec., is obviously, for purpose of comparison, the proper quantity to consider.

Now, on referring to the descriptive articles already mentioned, it is seen that Mr. Delaney's apparatus comprehends 7 circuits (six signalling, and one corrective of the synchronism) of 12 contacts each; in all (12×7=) 84 line contact points. These 84 line contacts are alternately disposed with an equal number of contact points connected to earth, which serve to partially discharge the line between the successive transmissions of current, so there is altogether 168 contact points or "plates," as they are generally called, in the circle traversed by the line brush.

Suppose the parts to be of the following demensions :—

	Inches.	Total.
Line plates, each	$\frac{1}{4}$ = .25 in. × 84 =	21.0
Earth " "	$\frac{1}{4}$ = .25 " × 84 =	21.0
Spaces between ditto	$\frac{1}{40}$ =.025 " × 168 =	4.2 = 46.2

The circumference of the circle is in this case 46.2 inches, and as it is traversed by the line brush 2 $\frac{8}{3}$ times in a second, it follows that a distance of (46.2 × 2.83 =) 130.75 inches per second is covered.

Now, as the length of time occupied by the brush in passing over a given line plate is the exact measure of the duration of contact made with the battery, for the transmission of a current, it is evident that (since 130.75 : ·25 :: 1 : ·0019) the current is in each instance presented to line for only (· 0019=) $\frac{1}{526}$ of a second.

Again, it will have been noticed in following these calculations, that with a given speed of rotation of the line brush, the width of the plates determines the length of time the current is put to line. This being the case, it is obvious that when the brush is passing over an earth plate, the line is fulfilling no function, it is idly discharging; consequently, with this arrangement the line is half of the time idle and its theoretical capacity is utilized to the extent of less than 50 per cent., the insulation wedges between the line and earth plates occasioning the slightly further loss.

That this disadvantage is inseparable from the system is evident, for the discharge of a line is always slower than the charge, and it is necessary in this system to obviate the possibility of an appreciable part of the charge due to the transmission of a signal between one pair of corresponding plates being communicated to the electro-magnets connected with the next succeeding pair.

There is in the foregoing figures, too, an explanation of the other deficiency of the system. The apparatus in operation transmits currents of only .0019 sec. duration; we have seen elsewhere that the time required to produce a signal (that is, to effect a full attraction and

movement of the armature of the receiving instrument) on a line of 100 miles of No. 6 iron wire is, by calculation, .0022 sec. The difference is so small that the figures may be said to agree. However, it is evident the transmitted current is barely sufficient to produce an effect; and, as the length of time required to produce a signal increases with the length of the conductor, it can be readily understood why the operation of the system is confined to comparatively very short circuits.

With the synchronous multiplex before us, its deficiencies discovered, and the causes thereof traced to an arithmetical certainty, it is an easy matter to define what the requisites are to produce an *ideal* system :—

1. The receiving instruments should be made responsive to single pulsations of an ordinary strength of current, so as to be independent of intermittances. This would economize the signalling capacity of the line.

2. The necessity for discharging the line after each pulsation should as far as possible be eliminated, so as to admit of minimizing the earth-plates and thus afford space for additional line plates. This would secure the furthest utilization of the signalling capacity of the line.

3. The system should be applicable to intermediate stations. This would render every one of the several circuits as readily available and generally adaptable as a single Morse line.

Now, the attainment of this perfection is not only possible, it is the next thing to an accomplished fact, as will be seen in considering the results of the writer's personal research in this particular department. These results are comprised in a new system comprehensively designated,

THE INTERCHANGEABLE WAY-WIRE MULTIPLEX.

As this system is somewhat different from its predecessors in the principle of its operation, it may be best introduced for consideration by a general statement of its characteristics.

The conception of it is based like the other synchronous systems on the well-known fact that the manipulation of a key by the most expert Morse operator is very slow compared with the rapidity with which an electrical effect can be produced, and further, on the ascertained fact that when signals are produced by pulsations of alternate polarity, + closing and — opening, 24 *contacts per second* (12 corresponding to downward movements or depressions, and 12 corresponding to uprisals of the key) is all that is necessary for transmission at the rate of 40 words per minute.

According to this latter finding it is only necessary to make connection between any two corresponding sets of apparatus once in every $\frac{1}{24}$ of a second, in order to intercept every movement of a given key,

and so produce precisely the same effect in the distant receiver as would obtain were the sending and receiving instruments continuously in circuit.

In order that this may be understood, the tape of a Morse register may be taken in an instance where signals have been embossed upon it at the rate of 40 words per minute. The length of a dot will be found to be $\frac{1}{24}$ of the length of tape passed over per second. Or, a sentence of 40 words may be written down in Morse characters on paper ruled with horizontal lines representing unit divisions, allowing 1 unit for a dot, 1 unit for the space between the elements of a letter, 3 units for a dash, 2 units for the space between letters, and 4 units for the space between words; it will be found that the entire sentence occupies 1440 divisions = 24 units per second, thus showing that $\frac{1}{24}$ *sec. is occupied in the formation of a dot or a space* in manipulation at the rate of 40 words per minute.

On the other hand, it is known that the time required for the production of a signal by electro-magnetism is extremely brief; only ·003 = $\frac{1}{333}$ of a second, with sufficiently sensitive yet practical apparatus, on an ordinary No. 8 iron telegraph wire 300 miles long, and in less time on a line of shorter length.

It is therefore obvious that the whole period ($\frac{1}{24}$ sec.) of each of 24 contacts that can be afforded in a second is not necessarily at the disposal of one operator.

Hence, if in every $\frac{1}{24}$ of a second the line wire is put in connection with a given key sufficiently long to produce one electrical effect, the balance of each $\frac{1}{24}$ of a second can be occupied in the production of electrical effects under other keys with which it can be successively connected. From this it follows that if the time required to produce an effect on a 300 mile line is only $\frac{1}{333}$ of a second, we can, theoretically, obtain in it as many as ($\frac{333}{24}$ =) 13 signalling circuits.

Now, it will have been seen in the description thus far, that the principal action hinges on the possibility of the brief transmitted current affecting the receiver, in such a way as to leave an impression upon it during the interval of the succeeding pulsations. That is, if a + pulsation is transmitted in the formation of a dot or dash, the armature of the receiver must be attracted and remain so until a — pulsation, transmitted in the formation of a space, reverses its position.

And it is also evident that the receiver must be extremely sensitive in order to afford the maximum number of signalling circuits on a given line.

To see how this is provided for, it will be remembered that in deal-

ing with the other systems just now, it was shown that a signal can be produced on a Hughes' magnet in $\frac{1}{33}$ sec. against $\frac{1}{100}$ sec. required for electro-magnets of other forms. In other words, the Hughes is 3 times quicker in its action.

Now, it has been found in the course of experiments made with reference to this system, that if an ordinary polarized relay is operated through the medium of an induction coil, the relay is rendered responsible to a single brief pulsation of current; whereas, when operated directly, three successive pulsations are required to produce a full attraction of its armature. That is to say, the combination with the induction coil furnishes a receiving instrument equal in celerity with the Hughes magnet, and should therefore be capable of response to a signalling current of $\frac{1}{33}$ sec. duration on a 300 mile line of No. 8 iron wire. By means of an automatic device, the induced currents communicated to the relay operate in only one direction dependent upon the polarity of the transmitted pulsation. Consequently its armature remains at rest against one or other of its limiting stops, according to the direction of the last current presented to it, and is unaffected by successive pulsations of the same polarity.

Now, having an economical method of signalling and the requisite apparatus therefor, it is only necessary to associate it with means for transferring the line wire from one set of instruments to another simultaneously, at as many stations as desirable on a line, in order to produce a multiplicity of signalling circuits.

In the references that have already been mentioned in connection with previous systems (viz., *Electrical World*, Vols. II, VI and XIII), the means whereby synchronism can be obtained and maintained between stations connected together in circuit are set forth in a sufficiently clear manner, to obviate the necessity for explaining in detail the specific arrangements that have been devised for that purpose in this instance. It will suffice to state here that motors at the terminal stations of a line are brought into unison by correcting devices. Currents regularly alternating in polarity are concurrently transmitted to line from both terminals; these currents conjointly operate the motors at the intermediate stations, and the result is a perfectly synchronous action throughout the entire system.

By means of this synchronous mechanism, a brush in electrical connection with the main line is revolved about the circle of contacts connected with the signalling apparatus, at all of the stations in circuit, with sufficient frequency to put the line in contact with each of the corresponding sets of apparatus once in every $\frac{1}{14}$ of a second; and at

each of the terminal stations the shaft that revolves the brush carries a commutator of a sufficient number of segments to produce 24 reversals per second of the main line battery which is connected with it.

The main batteries at the terminal stations are moreover reversely connected with the commutators, consequently + presented to line at one end is met by — presented at the other end; the currents combine in the line, and, as they are alternated by the revolving commutators, the line is traversed by regularly recurring + and — pulsations.

It will be seen, therefore, that the passage of the main line brush over the contact plates connected with the signalling instruments is concurrent with the presentation to line of any one phase + or — of the main line current. Hence, if the contact plates are arranged in series equidistantly, and corresponding to the segments of the commutator, certain of the contacts will regularly and invariably afford a path for the +, and the others for the — pulsations.

And, further, if the transmitting keys are provided with front and back contacts, respectively connected with the + and — series of the line plates, the levers of the keys being connected with the battery commutator, it is evident that when any given key is depressed or upraised it will, in its circuit, interrupt the path of one or other of the currents.

This being the case, the polarity of the current transmitted depends upon the position of the key in the case of each of the signalling circuits. And normally, when the key in any circuit is not being used, a circuit closing arm associated with it in the ordinary manner is closed and bridges both the back and front contacts, thus permitting both phases of the current to circulate.

Now, as the + and — phases of current are presented in each instance for $\frac{1}{24}$ of a second, during which time the line brush traverses one entire series of the contacts, it is clear that if the keys in some of the circuits were depressed and in others upraised, the current would be interrupted and re-established repeatedly, so that it becomes broken up in a succession of mere pulsations. The fact is, therefore, that each of the signalling circuits is operated by means of a single pulsation that recurs alternately + and —, every $\frac{1}{24}$ of a second, and the position of the key determines whether a given pulsation shall or shall not affect the receiving instruments that are in circuit with it.

It might appear at first sight that there is a chance of a movement of the key taking place between two successive pulsations, that would not be reproduced in the receiver; but a moment's consideration will show this to be impossible, since every movement of the key by the operator's hand occupies, at the very least, a period of time that is suffi-

cient for the line brush to sweep over the entire series of the circuits. There is, however, this possibility, that in a case where + currents operate to close the receivers, and — currents to open them, the sending key might be depressed concurrently with the presentation of a — phase of the current, and upraised concurrently with the succeeding + phase. In such a case it is evident the movement of the key would be lost on the receiver; this possibility is, however, obviated by means of a semi-automatic transmitter through which the movements of the key are communicated to the line circuit. The operation is simply this: If the key is depressed to form a dot, the lever of an electro-magnet, in local circuit with the key, is depressed, and remains in that position, after the key is upraised, until a + pulsation transmitted to line releases it. The lever in its upraised position affords a path for the succeeding — pulsation. A dot is thus transmitted. If the key is again depressed, the same operation is repeated; so long as the key remains open only — currents go to line; and when closed, + currents are transmitted. As the successive pulsations recur with the same rapidity as the movements of the key, it is obvious the latter cannot get ahead of the former; consequently, every movement of the key is reproduced in the receiver, the operation being precisely the same as if the key moved in exact unison with the recurring alternations of current.

There now remains only one other important feature to point out: It is, that as in this system the receiving apparatus is positive in action and responsive to one full pulsation of either polarity, it is not in any given circuit susceptible to the influence of the tailings of the charge in the line due to the transmission of a signal in the circuit immediately preceding. It is therefore sufficient to put between the successive line plates a very narrow segment for earth contact. Between the separate series an earth plate, as large as any one of the line plates, is provided to fairly clear the line of the charge of one polarity before the other is introduced.

Reverting for a moment to the explanation given as to how signals are transmitted, it will be remembered that the current pulsations are regularly presented, and it is the position of the keys that determines their circulation in the respective circuits. It will therefore be readily understood how intermediate offices can be introduced on the line; they have circles of line contact plates and the rest of the apparatus excepting the main line batteries and commutators, which are not needed; the transmitted currents pass through them, each circuit having its own pulsations to which the receivers respond. As at the terminal stations

so is it at the way offices, the position of a given key determines the circulation of the current. Normally, the circuit-closing arms of all the keys in a given circuit are closed, and the recurring + and — pulsations circulate in it. The opening of any one key, therefore, will affect all the receivers in the circuit, and they will follow its movements precisely as on an ordinary single circuit Morse wire.

The interchangeable feature of the system is also almost self-evident. Since the signalling currents emanate from both ends of the line, any one of the intermediate offices can ground a given circuit and work in either direction independently; or loop lines can be introduced and operated precisely in the same way as when let into a regular Morse circuit; or a number of offices may be regularly on one circuit while a certain other number may be on another, and these can interchange in the same way as if located on so many separate wires. Moreover, we have this very desirable feature, that in the normal condition the keys being all closed, the apparatus at an intermediate office presents no obstruction whatever to the passage of the currents; it may therefore be out of adjustment or otherwise disarranged without affecting the other offices in circuit, just as on an ordinary Morse line which is operative between offices whose instruments are adjusted and inoperative to those whose instruments are not adjusted or otherwise locally affected.

Now, from what has been stated, it is evident that we have here a system calculated to afford the highest possible degree of efficiency, and one that utilizes the capacity of the line wire to the fullest extent.

Of 13 circuits theoretically obtainable in a wire 300 miles long, we can count upon at least 9 for signalling purposes; we might do more than that, but recollecting that the number depends upon the length of the surface traversed by the line brush per second, the space equivalent to 4 circuit plates is only a liberal allowance to make for the synchronous circuit plate, the earth plate, and its minor segments and the insulation wedges. All these may be taken together and set down as *mechanical intervention*, and therefore a constant quantity; and in any calculation we make for a given line, we may subtract the equivalent of 4 circuits from the theoretical in order to determine its practical capacity. Thus, in accordance with the law of proportions elsewhere dealt with in this paper, we should obtain on an ordinary line 150 miles long as many as ($\frac{300}{150} \times 13 = 26, -4 =$) 22 signalling circuits.

How readily this can be done has yet to be ascertained. It will be remembered that in the remarks prefacing the description of this Way-Wire system, it has been stated that the perfection attainable in it is

the next thing to an accomplished fact. What has been herein described is mainly an hypothetical fabric—to use a big phrase—but it is a theoretical construction that is based on the results of and inferences from sound laboratory experiments. It yet remains to be seen whether all that is claimed for this system can be realized in actual practice.

Note.—It is not stated so, literally, but it is in effect: It is stated on p. 397, that, "The rapidity with which successive signals can be transmitted depends essentially upon the time required to charge and discharge the line." [This time, it is shown on p. 393, is on a No. 8 iron wire 300 miles long, about ·018 sec., and on an equal length of No. 6 gauge (·20 in diameter), the time required is about ·013 sec].

It is stated on p. 395, that the time required to produce an effect on the No. 8 wire was found to be with a Hughes electro-magnet ·003 sec.; and ·01 sec. is set down for an unpolarized electro-magnet of the ordinary form.

It further appears, on p. 395, that on a given line with one class of apparatus, the time required to produce an effect is "nearly in proportion to the length of the line;" and with the other class of apparatus the time required "increases in a much greater proportion than the length of the line." These statements have reference to lines of 300 miles and over, and it is therefore very safe to assume that for lines under 300 miles the time is at the most directly proportional to the length.

The obvious interpretation of all this is, that the time required to charge a line is the index of its signalling capacity. If we know the rate of charge of any two wires and the signalling capacity of one of them, we can, by a simple sum in proportion, determine the signalling capacity of the other.

Whence it follows, taking the figures quoted, that the time required to produce an effect on an unpolarized magnet on the 300 mile No. 6 line is ·0072 sec.; the proportion being ·018 : ·013 :: ·01 : ·0072. And the time required on a 100 mile length of the same line is ·0024 sec.; the proportion being 300 : 100 :: ·0072 : ·0024.

This result is practically the same as the ·0022 arrived at by the other calculation given in the paper. Besides, the interpretation of the above text, upon which the last mentioned calculation is based—(viz., that the time required to actuate an electro magnet is about directly proportioned to the length and resistance of the conductor)—is supported by the statement, in Prescott, Vol. II, p. 1110, that "the speed (having reference to the synchronous multiplex) is inversely proportional to the length and directly as the size of the conducting wire"; this is of course assuming that *the size* of the wire has reference to its conductivity.

DISCUSSION.

Mr. W. J. Camp, of the Canadian Pacific Telegraph Co., said he had read Mr. Keeley's paper, and, as far as he could judge at present, the system appeared quite feasible. To give a decided opinion upon it he would have to study it more thoroughly. The principal trouble with the existing multiplex or quadruplex systems, which are the only ones in practical use, is that of battery power. Mr. Keeley's system overcomes that, as it reduces the battery power required to about one-third. Mr. Camp.

The Wheatstone automatic system, which is largely used in England, and to some extent in the United States, did not answer very well for America, the percentage of errors in telegrams being largely increased by its use. Although it may appear that automatic transmission would reduce the number of errors, experience has proved that by direct manual transmission and receiving by sound, the very best results as to correctness are obtained. Another objection to the automatic system is the time occupied in getting the despatch from one point to another. Although the actual transmission over the wire is very rapid, a great deal of time is lost in preparing the paper tape to transmit and in translating the characters at the receiving office. If Mr. Keeley's system can be worked, this will be overcome ; and if his system will work between terminal offices, any way office can be worked as described.

Mr. J. Kennedy asked to what extent was the quadruplex system employed on the Canadian Pacific Telegraph? Mr. Kennedy.

Mr. Camp, in reply, stated that their quadruplex circuits were as follows:— Mr. Camp.

Canso, N. S., and St. John, N.B.	375 miles.
St. John, N.B., and Montreal	485 "
Montreal and Albany, N.Y.	350 "
Montreal and Toronto	350 "
Toronto and Buffalo	180 "
Montreal and Ottawa	125 "
Montreal and Sudbury, Ont.	450 "
Port Arthur and Winnipeg, Man.	430 "
Winnipeg and Swift Current, N.W.T.	515 "
Donald and Vancouver	450 "

Besides these they had a number of duplex circuits, the principal ones being Montreal and Chicago, Montreal and Winnipeg, and Winnipeg and Vancouver.

At St. John, N.B., the two quadruplexes were connected by automatic repeaters, and at Montreal one-half of the same was connected with a duplex to New York, thus practically giving New York a double circuit to Canso, and Montreal a double circuit to the same place. In other words, both New York and Montreal could work duplex with Canso at the same on the one wire east of Montreal. On the Ottawa circuit a single Morse wire to Deseronto is connected at Ottawa on one half, and the other half used for local business between Ottawa and Montreal.

One half of the Montreal-Sudbury and Port Arthur-Winnipeg "quads" is connected by a duplex, giving a double circuit to Montreal and Winnipeg. The second half of the Sudbury set is connected to a single Morse wire to Sault Ste. Marie, Michigan, and the second half Port Arthur and Winnipeg is used for local business between those points.

The circuits between Winnipeg and Vancouver are more complicated. One half of the Winnipeg Swift Current quadruplex is connected at Swift Current with a duplex to Great Falls, Montana, the other half with a duplex to Donald, B.C., where it is connected with one side of the quadruplex to Vancouver. A duplex is worked from Winnipeg to Donald (with automatic repeaters) and there connected with the other half of the quadruplex to Vancouver. Winnipeg thus worked two double circuits to Vancouver and a double circuit to Great Falls, Montana, employing two wires as far as Donald and but one from there to Vancouver. Some of the "quads" are only used in cases of emergency, such as extra press of business, or when some of the wires are interrupted. The quadruplex is worked from Vancouver to San Francisco, about 1130 miles, with automatic repeaters at Portland, Oregon and Ashland, Cal.

The Great North-Western Co., the speaker believes, has the following quadruplex circuits:—Montreal and Quebec, Montreal and Ottawa, Montreal and Toronto, Toronto and Detroit; he thinks this is the extent to which quadruplex is used in Canada besides the cable system between Sydney, C.B., and New York.

The Canadian Pacific Telegraph Co. works duplex nightly between New York and Winnipeg, and very frequently from New York to Vancouver or San Francisco. Intermediate or way offices cannot work

on these circuits, the offices which can do so, except the terminals, are where the automatic repeaters are placed,—for instance, St. John, N.B., can work on the Montreal-Canso system.

In the United States between such places as New York and Boston and New York and Chicago, the quadruplex is very largely used, there being sometimes as many as ten or more quadruplex sets between two cities.

CORRESPONDENCE.

Mr. Gisborne. Mr. F. N. Gisborne regretted being unable to be present at the discussion of Mr. Keeley's paper on the multiplex telegraph. It is, in his opinion, novel but practical, and may finally be adopted in preference to quadruplex or any present form of multiplex apparatus.

Mr. Pope. Mr. E. Pope said Mr. Keeley's paper sums up very fairly the good and bad points of various systems of telegraphy now in actual use; his proposed plan is most ingenious, and when fully developed will no doubt be an advance on the present multiplex systems. It certainly will be if it can be made available for a "way" wire, but in that direction the "way agent" is an unknown quantity which has to be taken into account, for the necessary skill to handle the instruments to be used is seldom found even in the larger "way" offices.

Mr. Keeley has noticed the difficulty of harmonizing the automatic reversals of current with the free motions of the operators' keys, and he applies a remedy which seems to be insufficient to prevent such a mutilation of signals as would be found destructive to proper work. It may be found necessary to give the operators a key system by which their signals will all be taken up and transmitted into the line automatically to suit the automatic reversals. In actual working it is doubtful if any reduction can be made in the size of the earth plates, as Mr. Keeley calculates on. The wire will require to be thoroughly cleared after each signal, as in the systems now used.

Mr. Bott. Mr. H. Bott said in the Delaney system one objection is, that during the passage of the brush over the ground plates the line is idle and its theoretical capacity not fully utilized. In the "interchangeable way wire multiplex" system, although the receiving apparatus is not susceptible to the influence of the preceding circuit, still the brush will have the same function to perform, the wire remaining idle during its contact with the ground plate, as in the Delaney system. Will the capacity not utilized in that system be gained in this? May not the induction from other parallel lines make it a very difficult matter to adjust so as to neutralize the effect of the induced current?

According to the theory advanced by Mr. Keeley, his system seems

to overcome one of the disadvantages of the other multiplex systems in use, in that it allows way offices to work by providing a separate circuit for them, instead of as now leaving the wire idle between the two terminal points.

Mr. A. A. Dion said Mr. Keeley had dealt so thoroughly with the subject in his paper that there is little to be said, except to endorse in a general way his statements as to the important part the "multiple" principle is destined to play in the telegraphy of the future, and to congratulate him on his discovery of the means to extend its present application and usefulness. Mr. Dion.

To those who have given attention to the subject of telegraphy, the beauties and advantages of the "Simple Morse circuit" and the many difficulties attending the operation of "Automatic" or "Complex Circuit" systems, are so evident, that any invention tending to increase the capacity of the line wire, while retaining the many excellent features of the pioneer system, should receive a hearty welcome. In none of the various systems now in the field have those features been preserved. The nearest approach to the realization of the desired conditions is found in the "Synchronous Multiplex" systems based on the following established fact, viz.:—

If a number of electro-magnets are successively put in circuit, each for a fraction of a second, with a line wire carrying a current of electricity, and if the operation is repeated with sufficient frequency, the effect on each electro-magnet will be practically the same as if it had been constantly in circuit with the wire, and a continuous, instead of a pulsating, current had passed through it. The writer is of opinion that Mr. Keeley is justified in the assumption, that the line of further improvement in telegraphy lies in the full utilization of the line wire in the manner above stated.

Among the desirable features of the "Simple Morse Circuit" partly realized in the "Multiplex" systems is the possibility of extending their advantages to "way" offices, a matter of considerable importance in many ways. It may, however, be a costly privilege, or it may be obtained at the price of so much inconvenience as to make it undesirable. The writer knows of a multiplex system where this may be done by providing at *every* office a battery capable of operating the *whole* line. When one station is sending, the batteries of all other stations are idle as far as that particular circuit is concerned. This is the principle of the English open circuit system which does not seem suitable for this continent. It never found favour in America.

Whenever the "Simple Morse Circuit" is mentioned herein, the American or closed circuit system is meant, which permits way-offices to be opened anywhere or closed without much trouble or expense. In that particular as well as in many others, the system under discussion would seem to be the *only one* possessing the facility of operation and the flexibility of the "American Morse" just mentioned. That alone would entitle it to the serious consideration of telegraph engineers and electricians. But its aims are higher still. It claims to increase by fifty per cent. the number of circuits heretofore obtainable in practice, and to treble the distance over which a wire has been so utilized.

The way in which this is accomplished by the combination of an induction coil with a polarized relay, so as to make the latter responsive to *single pulsations* of current of $\frac{1}{333}$ of a second duration, is ingenious and original. The property the armature has of remaining on its contact, after being once attracted, until forced back by a pulsation of opposite direction to that which produced the attraction, making it unnecessary to make contact between the line and any one set of apparatus oftener than once every $\frac{1}{24}$ of a second, etc.

To many persons who have not followed very closely the later developments in the applications of electricity, the matter of synchronism suggests serious difficulties; but the problem having been solved very efficiently in other "Multiplex" systems, there is no reason to anticipate any trouble in this case, as Mr. Keeley proceeded upon the same lines as his predecessors. The claims of the inventor are based on well known laws of electro-magnetism, and the writer thinks that the "Interchangeable Way-Wire Multiplex" is a healthy and promising infant, and that if all cannot feel enthusiastic about it, they can at least wish it success and watch its practical application with the attention it merits.

Mr. Keeley may not care to let us further into his confidence; but, in the hope of obtaining more light, the writer ventures to ask the following questions, which need not be answered if the information asked for is not yet ripe for the public:

1st. The keys, corresponding to any one circuit, being closed at all offices, the circuit not being used, the + and — pulsations will occur alternately every $\frac{1}{24}$ second. Will not the armatures of the polarized relays vibrate between their contact points in unison with the alterations of current in the line, sounding a series of dots; and if not, how are they prevented from doing so?

2nd. How many series of contact plates is it proposed to have in the circle? In other words, what will be the rotary speed of the brush?

3rd. It is not stated that a second wire is used to carry current to operate the motors. If the line currents are used for that purpose would the synchronism be affected if, perchance, all the keys in one station were depressed? Or is there a special circuit (without a key) including the motor? In that case the current through the motor would consist of alternate + and — pulsations of $\frac{1}{333}$ second duration, with intervals of $(\frac{1}{24} - \frac{1}{333} =) \frac{1}{26}$ second between them, and the motors must be constructed so as to respond to those detached pulsations. Is that the case?

Mr. George Black said that he considered the review of the various systems of telegraphy, introductory to the new system described, as very clearly presented and their value not under-estimated. The "Interchangeable Way-wire Multiplex" is, in his opinion, correct in principle, and the difficulties which may possibly be encountered in practice will no doubt be easily overcome. Mr. Black.

Mr. Keeley said he had now prepared diagrams, Plates I and II, to illustrate his subject. The absence of these at the time the paper was read and the necessarily brief description of the Way Wire Multiplex, given in the concluding part of his paper, left room, it appeared, for some misconception of his ideas. This, however, he believed he would now be able to satisfactorily clear away. Mr. Keeley.

Taking up the questionable points as they had been presented, Mr. Pope's objection as to the doubtful skill of the average way office operator to handle the instruments was well taken. The speaker was himself well acquainted with that feature of the business, and has in his plans provided for it by rendering the operations of the circuits independent of any local disarrangement of the apparatus. In the present everyday experience on a single Morse line, there are instances when the instrument at a given office on a way line is disarranged —"not adjusted." That office is practically inoperative for the time being; but it does not interfere with the exchange of signals between other offices on the same line. As the system proposed does not pretend to excel the regular Morse circuit in its characteristics, but rather to preserve them all intact, the writer has faith in the skill of the average way-office operator being found equal to the occasion, for all that is required of him. Mr. Pope noticed an apparent difficulty in obtaining a correspondence of the key movements with the regular alternations of main line current in the act of transmission. If it had been practicable to furnish in the paper the details

with reference to that feature, which the writer was unable to submit, this objection might not have been advanced. It would be seen presently how he had arranged for it; but supposing he were wrong and Mr. Pope right, it would be quite practicable to dispense altogether with the semi automatic function of the transmitter, and operate the circuits directly, provided that the main current alternations were increased sufficiently to furnish both phases of current during each position of the key. This would of course, on the basis of 40 words per minute, reduce the number of signalling circuits one-half; but even allowing that the number would be 5 on a 300 mile line, and 11 on a 100 mile line, *adaptable to way stations;* whereas, with Delaney's system, the best of those heretofore introduced, 6 circuits on a 100 mile line limited to terminals, is all that can be obtained. The next and last point advanced by Mr. Pope is the supposed necessity for effecting a complete discharge of the line between the successive circuits. This was due to a misconception. The explanation of this feature given in the paper was necessarily meagre. There is this difference between the writer's method of signalling and that of previous methods. Take five successive circuits in Delaney and Calahan's first form of the Synchronous Multiplex, or in Lieut. Patten's system; let 1, 3 and 5 be *closed*, and 2 and 4 *open*. The line has to be traversed by currents successively as follows $\overset{+}{1}\ \overset{-}{2}\ \overset{+}{3}\ \overset{-}{4}\ \overset{+}{5}$. Unless a + current is obliterated, the succeeding — is ineffectual; and unless the — current, in its turn, is obliterated, the succeeding + will not be effectual. Now, taking the same circuits according to the writer's method, the line would be traversed by $\overset{+}{1}\ \overset{0}{2}\ \overset{+}{3}\ \overset{0}{4}\ \overset{+}{5}$ and, after a discharge, by $\overset{0}{1}\ \overset{-}{2}\ \overset{0}{3}\ \overset{-}{4}\ \overset{0}{5}$, since the + and — phases, in series, take turn about. The narrow earth segments introduced between the succeeding line plates prevent an accumulation of the charge in the line which would occur when several successive circuits were closed. For instance, without them, it might be (graphically) $\overset{+}{1}\ \overset{+}{2}\ \overset{+}{3}\ \overset{+}{4}\ \overset{+}{5}$ in this case the tailing of the charge from 3 would operate in 4, which should otherwise be unaffected. With the segments, the charge would be $\overset{+}{1}\ \overset{+}{2}\ \overset{+}{3}\ \overset{0}{4}\ \overset{+}{5}$; in this case the charge is kept down, so there is a very slight tailing into 4. In Delaney's (improved) system, that dealt with in this paper, the latter condition, if narrow segments are used, would obtain; and as the receivers are worked on intermittent currents, it is necessary to

obviate even the slight tailing (by putting in wide segments), in order to allow the armature to fall away. According to the writer's arrangement, the receiver is positive in action, moved one way by a *full* + and the other way by a *full* — pulsation; and in it a + pulsation never occurs at the same time as a — tailing, or a — pulsation concurrently with a + tailing, in consequence of the + and — phases being in series; so the slight tailing (which is always of the same sign as the current following upon it) from one circuit into the other is wholly ineffectual.

In reply to the remarks of Mr. Bott, in Delaney's system the discharge plates are uniform in size with the signalling plates, whereby 50 per cent. of the line-time is lost. Again, in that system, 34 contacts per second are required to accommodate the sending operator's manipulation. In the Way Wire Multiplex system, on the other hand, only very narrow segments are required between the signalling plates, for the purpose explained in the reply to Mr. Pope's objection; and only 24 contacts per second are required for the operator's accommodation. It must therefore be very clear that the signalling capacity of the line will be utilized to a far greater extent in the latter than in the former, in fact, to its *greatest extent*, both theoretically and practically. As regards the interference from induction from neighbouring lines, there could be none, for the reason that the receivers proper are in local circuits and actuated through the medium of induction coils, whose currents are ineffectual excepting when occasioned by a full pulsation of the main line current. A careful perusal of what is stated in the paper with reference to quadruplex circuits will show that this matter of induction has not been disregarded in the devising of the speaker's new system. It was no doubt in consequence of Mr. Bott's experience with that class of multiple circuit systems that he suggested the possible difficulty of interference.

The remarks of Mr. A. A. Dion are fully answered in the explanatory notes accompanying the diagrams, Plates VIII and IX. The relay levers do vibrate in response to the current alternations. There could be no objection to this, however, because it need only occur, so far as the sounders are concerned, on one or more of the circuits that may be set apart for calling purposes. The moment actual transmission begins, the circuit is under control of the key, and the continuous vibration cannot then occur. The other two questions, as to the number of signalling plates and speed of rotation of the line brush, are answered in the diagram, Plate I; they are there set down as 8 series, with 3 revolutions of the brush. Obviously it might be 4 series with 6 revolutions, or

any other modification resulting in 24 alternations per second; but it is more convenient to obtain perfect synchronism with comparatively low speed, and 3 revolutions per second is calculated to afford the best results. Mr. Dion was mistaken in supposing that the intention was to operate the motors directly by the main currents, by pulsations recurring every $\frac{1}{24}$ of a second. As indicated in Plate II, two circuits are set apart for the operation of the motors, by means of receiving relays actuated in the same way as those for signalling. These relays are not connected to all of the series, and are only brought into operation at every half revolution; the one overlaps the other in the matter of closing and opening by the length of one series of contacts. Each is therefore actuated for ($\frac{1}{8}$ + $\frac{1}{24}$) a trifle over $\frac{1}{8}$ second, so there is nothing at all delicate about it.

Exception has been taken to that paragraph on page 256 in the paper which reads :—

"*Now, having an economical method of signalling and the requisite apparatus therefor, it is only necessary to associate it with means for transferring the line wire from one set of instruments to another simultaneously, at as many stations as desirable on a line, in order to produce a multiplicity of signalling circuits.*"

As he regarded it, this paragraph, read in a general way, bears a liberal interpretation such as was intended, and there is nothing extravagant in its composition; but he was told that one might just as well argue in the following strain :—

"Now that we have a horse that has run one mile in three minutes, and a car capable of holding fifty passengers, all we have to do is to attach the horse to the car and carry the passengers at the rate of twenty miles an hour."

Of course, this latter argument is preposterous; and in looking for the analogy that is assumed to exist between it and the one quoted from his paper, the writer finds that the latter has been construed as disregarding the element of counter-electromotive force that is introduced into circuit by the exclusion of way circuit apparatus. He has therefore to explain that this possible impediment to the practicable operation of an unreasonable number of way offices in any one circuit has not been overlooked. In the paragraph alluded to, the expression is "at as many stations as desirable." As is known in practice it is very rarely that more than two or three offices are simultaneously handling the same despatch, so it would be idle to have apparatus included in circuit where there in no occasion for it. His idea is to have on a line of 15 or 20 stations a system of multiple circuits, one or more of

which are set apart exclusively for calling purposes. All of the offices are included in these circuits,—some in one, some in another, as will be found most convenient. When the operator at a given office has answered his call, he switches his signalling apparatus into one of the other circuits designated by, or predetermined for, the office that has called him. In this way the circuits can be utilized to the best advantage. As for the multiplicity of offices on the calling circuits, the counter E. M. F. presented by their apparatus need not be taken into account, for its deleterious effect consists in hampering the rapid transmission of signals, and on calling circuits speedy signalling is not at all requisite. He must here emphasize the fact that in designing this system, he has been guided by thoroughly practical considerations throughout. He could now perhaps to some advantage present a further and fuller explanation as to the operation of the system, having reference to the drawings Plates I and II. .

It will be understood, in view of the descriptions already given in the paper, that the conditions for operation comprehended 24 reversals of current, that is 12 + and 12 — alternations per second. And as it was shown that this provision is necessary for the transmission of signals at the fastest practicable rate of Morse transmission, and since the downward movements of the key are reproduced by the currents of one polarity, and the upward movements by the currents of opposite polarity, it is obvious that the key movements must be brought into correspondence with the regularly alternating pulsations.

The means whereby this correspondence is effected is shown in Plate I.

In the act of transmission the opening of the switch S corresponds to an upward movement of the key K; this, as already explained, allows a — phase of the main current to pass, and interrupts the + phase. The relay R responds to the — phase, and the lever l rests on the back stop b. If now the key K is closed, the lever Tr of the transmitter will be drawn down, and a circuit, independent of the key K, will be closed through the magnet Tm, by the lever Tr, its lower stop, the dotted lines battery Tb and the lever l and back stop b of the relay. So, if the key is now upraised, the transmitter lever will remain depressed. In this position it affords a path for the + pulsations of current. The first + pulsation passing through it will actuate the lever l of the relay, and carry it from the back stop b to the front stop f, where it will close the circuit of the sounder So. The instant the lever l leaves its back stop b, the transmitter lever will be released and upraised.

As this effect is produced within a quarter of a second of the

upraising of the key, and as it is physically impossible for the manipulator to depress the key again within that brief space of time, it is clear that the uprising cannot be prevented by any subsequent depression of the key.

But in order that the uprisal of the lever Tr may be effectual, it must remain undisturbed for a brief space (not exceeding $\frac{1}{24}$ sec.) to allow the next — phase of the current to pass.

It is therefore necessary to obviate the possibility of a downward movement of the key during that period affecting the position of the transmitter lever. A further inspection of the circuits will show how this is done.

If, at the moment the lever l of the relay R is brought against its front stop f, the key K is open, a circuit is formed by the contacts l, f, including the batteries Tb Sb and the sounder So. If, now, the key K is depressed, the lever Tr of the transmitter will be unaffected, because the battery Sb is in shunt with Tb, and its current through the magnet Tm is opposed to that of Tb, and renders the power of the latter inadequate to pull down the lever Tr. The instant, however, that a — pulsation passes to line, the lever l of the relay R is carried away from the stop f; the disconnection opens the circuit described through So, the current of Sb is withdrawn, and that of Tb alone operates by way of the key K through Tm, and the transmitter lever is pulled down. This action all occurs within $\frac{1}{24}$ of a second of the key movement.

As each movement of the key occupies no less than $\frac{1}{24}$ of a second, and the reversals of current occur with that frequency, the key cannot act faster than the currents.

When it happens that the downward and upward movements of the key are respectively concurrent with the + and — phases of current, the lever l of the relay in responding will not interfere with the position of the transmitter lever Tr, because the balance of current obtaining when Tb is opposed by Sb (though inadequate to draw it down when upraised) is sufficient to hold it in position after it has been depressed by the action of Tb alone in circuit with the key.

Each upward and downward movement of the key is therefore faithfully reproduced in the main circuit. The lever l of the relay R follows the movements of the key as shown; and the same currents that affect the relay R affect every other relay that is included in its circuit.

In further explanation of the brief description given on Plate II it should be pointed out that the synchronous motors are purely local

in action, though controlled by the main line receivers Ra Rb. In consequence of this, the main circuit is quite independent of the way station conditions, because normally all of the circuits are connected "through;" and if the apparatus at a way station gets out of adjustment, the entire plant presents as it were a unit of conductivity in the circuit, permitting the uninterrupted passage of the regularly recurring currents between the terminal stations. On the other hand, when the way station apparatus is in proper working order, each of the multiple circuits presents the characteristics of a single Morse line; any one or more of which can be grounded without interfering with the other circuits. In the diagram the ground switches E at the way office indicate how this is done. Of course in such a case the circuit is operated by the currents emanating from one end alone, as in a regular Morse line.

In the actual arrangement of the way office circuits, spring jack switches are provided for the ready introduction of the signalling apparatus into circuit, or on either side of an inserted ground wire in any circuit.

With this further explanation the writer thinks he has about covered the ground, and believes he has amply justified the high opinion of his new multiplex system which has been expressed by the general superintendent of the Government telegraphs, Mr. F. N. Gisborne.

It is also satisfactory to have such a favourable expression of opinion regarding his proposed system from Mr. Camp, who, from his wide experience as electrician to the Canadian Pacific Telegraph Co., is thoroughly cognizant of the requirements of the general telegraph service. The information Mr. Camp has given affords a good idea of the extent to which the quadruplex systems of multiple circuit telegraphy are now in use, though their operation is confined to terminal stations, and this argues the existence of an increasingly wide field of application for a system of the kind dealt with in the paper, which, while affording a larger number of circuits than is obtainable by the methods of quadruplex construction, is adaptable for the accommodation of intermediate and terminal stations.

Thursday, 23rd October.

JOHN KENNEDY, Vice-President, in the Chair.

The discussion of Mr. D. H. Keeley's paper on "Developments in Telegraphy, etc.," occupied the evening.

Thursday, 6th November.

E. P. HANNAFORD, Vice-President, in the Chair.

Paper No. 45.

THE ERRORS OF LEVELS AND LEVELLING.

By Prof. C. H. McLeod, Ma. E., M. Can. Soc. C.E.

PART I.—THE DEFECTS OF LEVELS.

As is well known, levels are manufactured from glass tubes by grinding the inner surface of the tube with emery powder placed on an arbor rotating in a lathe, the arbor having been previously turned from a template to the desired curvature. The tube should be slowly turned about its axis, so as to present the whole of its inner surface to the arbor, giving when the grinding is completed a similar internal section for all planes through the axis of the cylinder. The surface intended to be uppermost should then be brought to the highest possible degree of polish. This completed, the ends are temporarily plugged and the tube filled with liquid. The level is then tested on a trier, and if the curvature proves to be uniform the ends are hermetically sealed and the centre line of the upper surface graduated in equally distant divisions.

The levels used on the ordinary engineering instruments can be made with sufficient accuracy by this method. In the practice of one of the best American makers, all levels of less delicacy than 5″ per division of 2 mm. are machine made, in this manner. For levels having a scale value of from 1″ to 5″, such as are used for astronomical and geodetic instruments, it is necessary to apply local corrections after the level is first roughed out on the machine. As the level must be tested after every correction, this is a very tedious as well as most delicate operation, and indeed not infrequently ends in failure. It is very important that the upper interior surface should have the highest possible polish,* and be entirely free from grains of emery or other foreign particles. The glass employed should be of the hardest and least

*Some makers maintain that the highest polish does not give the best results, for what reason is not known to the author.

hygroscopic kind, in order to avoid any deterioration of the accuracy of the level through chemical action on the glass by the liquid filling. The tube should be of uniform bore and thickness. The liquid most commonly employed for engineering levels is alcohol. A certain percentage of ether is sometimes added to the alcohol, in order to obtain greater fluidity and therefore increased sensitiveness in the level. Ether of naphtha is also sometimes used for instruments of this class. For the highest class of levels the filling liquid generally employed is sulphuric ether, with sometimes a small percentage of chloroform.

Too little attention is paid to the mounting of bubbles. The usual method of enclosing the glasses rigidly in a metal tube may give rise to such serious changes of form in the level as to render it wholly unreliable. Some examples of change of form due to the mounting will be given hereafter. Levels for "precise" work of all kinds should be connected with the frame at only two points, and should then rest on some yielding material such as cork or sheet lead, and be held in place by light strips of metal; the ends of the tube abutting against a piece of cork. The more delicate levels having a scale value of 3″ or under require protection from air currents or from rapid changes of temperature, due to radiation from surrounding objects, and should be enclosed in a glass tube. The ends of such levels are chambered—that is there is a diaphragm cutting off from $\frac{1}{2}$ to 1 inch of the end of the tube, the diaphragm having a small hole in it—to admit of adjusting the bubble to a standard length under varying temperature.

Having thus briefly reviewed the construction of levels we are brought to the object the writer has in view,—a consideration of some of the defects to which levels are subject.

Irregular Curvature.—This gives rise to a shift in the zero position of the bubble with each change in the temperature of the liquid, since the bubble shortens or lengthens more towards one end than the other as the liquid expands or contracts. An engineer's level having this defect will, when placed in adjustment at any one temperature, not be in adjustment for any other temperature. Where the level is used to measure angular values, as, for example, the inclination of the axis of an astronomical transit, it is obvious that the result will depend on the position of the bubble on the scale. Irregularity of curvature is unfortunately a common defect in engineering levels, and to it are no doubt due many of the discrepancies so often met with in levelling. Where the range in the scale value is not great, such an instrument may, with proper precautions, be used on ordinary engineering work, but would be quite inadmissible for astronomical purposes, where the scale value is the important factor.

A level which was made for McGill College some years ago, to be used as a striding level for a transit-theodolite, has a scale value running somewhat as follows, from end to end :—12", 37", 34", 22", 20", 3", with a portion of the ends flat or of reversed curvature. This instrument is of course worthless. When the fact is added that its maker has made and can make good levels, it will be acknowledged that every level, no matter what may be the reputation of the maker, should be subject to most careful test before being put into use.

Difference of sectional area of the ends of the tube also gives rise to a shift in the zero, since for a given change of temperature the air space at one end will be altered in length to a greater or less extent, according as it is towards the smaller or larger end of the tube. Where the grinding tool has been carefully applied around the whole circumference, the axes of the grinding arbor and tube being maintained parallel to each other during the operation, and the tube is of fairly uniform diameter, the condition of equality in the two ends is most perfectly fulfilled.

Roughness of the upper interior surface, arising from imperfect polish or from small particles of emery adhering to the glass, will give results which at first sight closely resemble those arising from irregular curvature. The bubble is held back by the rough particles, while the level is turned through a considerable angle, thus giving the appearance of increased scale value, and when the bubble finally breaks away, it moves through several divisions of the scale as if the curvature at that point were very much flattened out. A level, which was recently sent to the writer for examination, gave a reasonably uniform scale value for long runs, but when it was examined more closely showed great irregularity. Two points were found on the tube, at which the tests showed there must be some obstruction. In one position the bubble held through a change of inclination of 6". Examination with a magnifying glass revealed very minute particles of emery embedded in the glass at each of the points. After these were removed the level was found to be of very uniform scale value and sensitive at all points. Such a defect in an engineering level would render good work impossible, and would, in addition, be very annoying to the observer, inasmuch as it would be difficult to keep the bubble in the centre, unless indeed the obstruction happened to be at one end of the bubble when in its central position. The common defect of sluggishness and uncertainty in the position of rest is no doubt largely due to a rough surface, though doubtless also to some extent arising from the character of the liquid filling.* When there is such roughness of surface the position of rest of

* For effect of length of bubble on sensitiveness see Discussion.

the bubble is noticeably affected by the velocity with which it moves. When the position of the level is quickly altered the bubble over-shoots its mark and is held beyond the proper resting place. When, on the other hand, the level is very slowly moved, the bubble will not quite reach its true position of rest. In these cases a slight tap on the glass will usually suffice to bring the bubble to its true position. Up to a few years ago all the levels the writer had met, of the manufacture of a certain well-known London maker, had this defect. The level of the telescope of one of the 5 in. transit instruments in McGill College, the scale value of which is 25″, may be made to take up a position in this way, anywhere within a range of 7″, or up to a maximum of 3.″5 from its true position.

Levels are subject to change of form, either from a change in the glass itself or from the pressure due to change of form of the mounting, under the influence of temperature or otherwise. The latter may be guarded against by a proper form of mounting. The former, whether from permanent structural changes in the glass or from temporary changes under varying temperature, can only be met by an investigation of each individual level. If there be a permanent change of form there is of course liability to an irregular change of curvature, rendering the instrument worthless as an instrument of precision. The only example of this kind of change which has come under the writer's notice is an excellent level made by one of the best American makers. It is described by the maker as made from the best kind of Bohemian glass. It is needless to state that the possibility of any change of form is stoutly denied by the maker. Here, however, is the evidence in the case:—

Purchased in April, 1883, and forwarded by the maker to Prof. W. A. Rogers, then of Harvard College Observatory, for examination and determination of the scale value. The level was placed in wyes attached to the cube of the meridian circle of Harvard College Observatory, and adjusted so as to be parallel to the optical axis of the telescope. The scale values were read off on the circles in a series of seventeen separate determinations, extending from April 6th to April 25th. The resulting mean value of one division was $2.''19 \pm 0.''02$.

The level was then forwarded to Montreal, and has been in continuous use as a striding level for an astronomical transit up to date. It has received two severe jars, falling from the transit instrument to the floor,—first in June, 1883, and the second time about one year afterwards. On April 1st and 2nd, 1884, the scale value was determined on a level trier in the workshops of Messrs. Hearn & Harrison,

and gave a mean value, from three sets of sixteen determinations each, of 2″.40 with an inappreciable probable error. The value of one revolution of the screw on this trier was measured by comparison with an Elliot Bros. $\frac{1}{1000}$th gauge, which was itself verified by comparison with a standard bar by Professor Rogers.

During the years 1889 and 1890 several determinations at different times and under various conditions have been made on a level trier in McGill College, the screw of which has been compared with the gauge above referred to; the results of these comparisons are given below:—

Date	Temperature of the air.	Length of Bubble.	Resulting Scale value.
1889			
Jan. 30th.	7°	51 mm.	2.″63
May 16th.	62°	37 mm.	2.″48
July 15th.	69.°5	35 mm.	2.″56
July 15th.	69.°5	54 mm.	2.″58
	At 52.°0	Average value in 1889 =	2.″56
1890			
Feb. 22nd.	75°	51 mm.	2.″56
March 6th.	15°	39 mm.	2.″60
Sep. 20th.	65°	43 mm.	2.″51
	At 52°	Average value in 1890 =	2.″56

In order to discover if the change in form was in any way due to straining by the frame, the glass tube was removed from its frame and binding screws immediately after the test on Sept. 20th last, and in one hour was again examined and gave the same result. It was again examined, forty hours after removal from the frame, with the same result. There has undoubtedly been a decided change of form in the glass, and that, as was to be expected from the method of mounting, without external strain. Fortunately there is no serious change in the uniformity of the curvature. The final form which the glass now seems to have attained may have been reached several years ago, but certainly not within three years after it had left the hands of the maker. These results would point to the desirability of the finished levels being kept in stock for one or more years by the makers, in order to give time for any change of form to reveal itself. Such inquiry as the writer has been able to make has failed to discover a maker who adopts this

precaution. It is well known that a similar trouble has arisen in the case of the glass used for thermometers, but here the makers recognise the need of seasoning the glass before the thermometer is graduated and put on the market.

An examination of the table given above will also show a slight change of scale value, due to temperature. Although small, amounting only to about 0."0015 per degree Fah., it is of quite sufficient importance to be taken into account in a longitude determination, amounting as it does to over one-tenth of a second of arc for our average range of mean temperature in the year.

The writer is unable to offer any observations of his own in illustration of temporary changes of great extent in a level, unstrained by its mounting; but that there are such, and very serious ones, rendering the instrument quite unfit for delicate measurements, the following extract from a paper read at the Montreal meeting of the American Association for the Advancement of Science, by Prof. W. A. Rogers, will show :—"In "order to show the necessity for repeated and continuous observations "for the determination of the value of one division of the level, I record "here my experience with the companion level of the instrument known "as the Russian transit" (H. C. Observatory). "It was made in the "workshop of the Pulkowa Observatory.

"I began the observations about 8 o'clock in the morning of Nov. 13, "by comparing the readings of the circle with bubble first at the mid-"dle of the tube and then at the extreme end. Proceeding in this way "with each five divisions in succession, I was surprised to find, not only "a continued diminution of the value of one division, but a well-defined "shifting of the zero of the level. By noon I had nearly completed the "examination for the first half of the divisions. I then opened the "shutters for an observation of the sun. After an interval of ten "minutes, observations with the level were resumed, when it was found "that the value of one division, determined from the same space as "before, had increased by one-fourth of its mean value. It will be "sufficient to give in illustration the results of the observations on three "days.

1881.	Nov. 13th.	Nov. 14th.	Nov. 15th.
"Shutters closed	1 div=1.76" Th.=38°	1 div = 1.20" Th. = 40°	1 div = 2.06" Th. = 47°
"Shutters open	1 div=2.08" Th.=65°	1 div = 2.06" Th. = 70°	1 div = 1.78" Th.=86°"

Subsequent observations made under different conditions confirmed these results. Professor Rogers adds :—"It is hardly necessary to say

"that this level has been discarded as worthless. On the other hand, "the mounted level furnished with the Russian transit proves to be an "excellent one."

Here, then, are two levels made in the same workshop,—the one proving to be a good instrument, the other totally unreliable. A difference in the quality of the glass is the cause to which one would naturally refer this discrepancy, and this suggests an investigation of the permanence of form of the different kinds of glass, one which, so far as the writer is aware, has not yet been undertaken. The peculiar behaviour of this level, under the conditions of the test imposed, emphasizes the necessity of shading levels from the direct heat rays of the sun, a practice which is always insisted on in geodetic levelling, and which with little trouble might be adopted for the more important lines of levels in railway or canal work. A shade over the level is also important on account of the errors in reading the bubble, arising from the sun's rays falling obliquely upon it, giving a different illumination to the opposite ends.

Examples of change in the form of levels due to the varying strain in the mounting are only too abundant. In two Dumpy levels, in which the glass tube is held in a brass case and plaster of Paris, the scale values were determined as follows :—In one 21."5 at 66° Fah. and 17."1 at 20° Fah., and in the other 26."7 at 67° Fah. and 24."0 at 20° Fah., giving respectively changes of 1" for each 10° and 17° of temperature. The mere change of scale value is not the important point in such levels, but the associated circumstance, of which there can scarcely be a doubt, that a change in the zero of the level takes place with each change of scale value, putting the instrument which may have been placed in adjustment at a given temperature out of adjustment for any other temperature.

Since the introduction of ether as a filling fluid in levels, it has been found that in some level tubes so filled a deposit has occurred on the surface of the glass, the accuracy of the instrument being in consequence either greatly impaired or destroyed. The rough particles hold the air bubble and prevent that freedom of motion so essential in a good level. Dr. F. Mylius* has shown that these deposits occur through the action of the small quantity of water remaining in the ether, on the potash or soda in the glass. It is a matter of very great difficulty to fill a level tube with perfectly dry ether. Dr. Mylius used eosin as a re-agent in his investigation since it imparts a light yellowish colour to ether† and gives a bright red colour to water.

* Zeitschrift für Instrumentenkunde.

† Perfectly pure anhydrous ether is not coloured by eosin.

By adding some eosin to a tube filled with ether at the ordinary temperature of a room, and then lowering the temperature of the tube and the liquid considerably, small globules of water were found to be separated from the ether and to deposit themselves on the walls of the tube, becoming visible by reason of the bright red colour caused by the eosin.

He demonstrated also that these small particles of water, retaining their places, very shortly became saturated with potash or soda from the glass, and that after the lapse of a few weeks small particles of potassium or sodium compounds appeared within the drops. Where an acid is present in the filling material—as is usually the case—the deposit will take place in a crystalline form. Dr. Mylius and others have found that these deposits are more likely to occur in glass rich in alkalies, while in those having a large proportion of lead or zinc they are less likely to occur. The harder the glass the less likelihood is there of the deposits occurring. Also that they are more likely to occur where the surface is rough than where it is highly polished. To demonstrate this he roughened a delicate level tube previously uninjured, and found after the lapse of some weeks deposits occurring on the roughened surfaces.

Where such substances as alcohol and water are used for the filling material, the formation of crystal is prevented since the alkalies extracted from the glass will go into solution. Alcohol is, however, not sufficiently mobile for delicate levels. Experiments on the use of other fluid substances, such as benzoline, petroleum, and chloroform, have been made, but in them also the deposit of water occurs. The solution of the difficulty seems to lie in a proper selection of the glass. Flint glass having a large proportion of lead is not suitable owing to its softness and liability to alter its form. The choice of glass would seem to lie between Bohemian glass containing lime, thermometer glass containing zinc, and crystal glass containing lead.

When we consider the many defects to which a level is subject, it becomes obvious that it is an instrument which, while it is capable of yielding results of the highest accuracy, is also one to be used with great precaution. In fact, it can only be considered an instrument of precision when subjected to careful examination and test during the period covered by the observations in which it is being employed, and under conditions similar to those in which it is being used.

THE ERRORS OF LEVELS AND LEVELLING.

By Prof. C. H. McLeod, Ma.E., M.Can.Soc.C.E.

PART II.—ERRORS OF LEVELLING.

In considering the errors of levelling, reference will only be made to such operations as are ordinarily included under the name of spirit levelling, omitting any reference to trigonometrical levelling, in which the spirit level plays an equally important part. It will first be proper to remark that spirit levelling may be broadly divided into two classes: The ordinary levelling undertaken in connection with railways, canals, drainage, etc.; and "geodesic" or "precise" levelling, where the highest attainable accuracy is sought in fixing the elevations of inland points with reference to a common mean sea-level datum. Nearly all European countries are carrying out such systems of levelling in connection with trigonometrical surveys; and in the United States many thousands of miles have been run under the direction of the Coast and Geodetic Survey, the Lake Survey and the Mississippi River Commission. Some few hundreds of miles have, the writer believes, been levelled in Canada by precision methods, but he has not the details before him.

The instruments employed in spirit levelling may for convenience be divided into three classes,—the dumpy, the wye, and the precision level. The form of the dumpy and wye as employed for ordinary levelling need not be described here. The precision level appears under a variety of forms. Those which have been used in the best European work and in America are of the wye type. The level tube is detached and used as a striding level on the collars of the telescope. One wye is moveable in a vertical direction under the control of a micrometer screw, in order to obtain the small final adjustment necessary to bring the delicate level employed to a central position on the scale. There is a wide range of scale value in the levels employed in the two classes of work, and also amongst the individual instruments used in each class. This divergence is much more marked in the ordinary levelling instruments than in the geodesic instruments. In illustration of this point, the

scale values of the levels (as they came from the hands of the maker) belonging to McGill College are given in the table below. The scale values employed for geodesic instruments are usually within the limits of 3″ and 6″ per division of 2^{mm}; equal respectively to 3.75″ and 7.5″ per div. of 0.1 in., the length of the division on the levels referred to below.

SCALE VALUES at 65° Fah.

Kind of Instrument.	Maker's Name.	Scale value per div'n. of 0.1 in.	Optical powers.
12 in. Wye level.	Hammersley.	75″	18 and 26
14 in. Dumpy level "A."	Do	21″	18 " 26
14 in. do " "B."	Do	26″	20 " 25
14 in. do "	Stanley.	27″	20 " 25
14 in. do "	Troughton & Simms.	14″	18 " 30
18 in. Wye. "	Buff & Berger.	12″	37

The optical powers in this list will be referred to hereafter.

Before proceeding to a consideration of the errors of levelling, it will be necessary to review briefly the methods of adjustment in the several forms of instruments, and in this connection certain defects of construction will most conveniently be referred to.

The object of all methods of adjustment is to bring the line of sight parallel to the line tangent to the inner surface of the level tube at its zero point,—this line will in this paper be referred to as the "bubble-axis." In the dumpy this condition can only be reached by the direct method of reading the rod on two "pegs," the difference in the level of which is known, one point being near the instrument while the other is several hundred feet distant, and shifting either the position of the cross hairs or of the level tube, until the readings give the true difference in level. The only error in this method is the slight one due to the curvature of the earth, amounting to about $\frac{1}{100}$th of a foot in 600 feet, and to one-quarter that amount in 300 feet.

The method usually employed to obtain the difference in level of the pegs is by setting the instrument at a point midway between them. The errors of the readings then being the same, the difference is the true one. A second method of determining this difference of level, which is not so generally practised and is perhaps not known to all engineers, is as follows:—First set the instrument over one of the pegs, so that the eye end will just swing clear of the rod, held vertically on the peg. When the instrument is level, view the rod through the

telescope, with the eye at the object end; the centre of the small circular portion of the rod thus seen can be accurately estimated and its position read by the aid of a pencil or knife edge held against the rod. Then read the rod as usual on the distant peg. Now move the instrument over the second peg, and obtain a reading of the rod as in the case of the first peg. Then read the rod on the first peg which is now the one distant from the instrument. If we call the difference of the rod readings in the first position of the instrument m, and the difference of those in the second position n, then the true difference in the elevation of the pegs is $\frac{m-n}{2}$. Results thus obtained, being from four separate readings instead of two, and being independent of the accuracy of any horizontal measurement, are susceptible of greater precision than the usual method. The instrument and rod are now in position for the necessary adjustment, and the distant rod reading will be corrected by the above amount.

It is customary to adjust the wye level by the indirect method. The line of sight being examined for coincidence with the axis of the collars by revolving the telescope in its wyes, the bubble-axis is then tested for parallelism with the bearings of the collars by turning the telescope end for end in its wyes, and the necessary corrections applied. This method is based on the assumption that the collars of the telescope are true cylinders, and have equal diameters—an assumption which is often wide of the mark. In the case of one level used by the author, the error due to this cause amounts to somewhat over $\frac{1}{100}$th of a foot in 100 feet, a condition of adjustment which should be quite inadmissible for good railroad levelling. It is not an uncommon circumstance, in his experience, amongst users of wye levels, to find the fulfilment of the first portion of this test—the revolution of the telescope in its wyes—accepted as a guarantee of the perfection of the whole. Such an error of judgment is of course impossible with persons acquainted with the theory of the instrument; but alas, the holder of the position of "Engineer" in this free country of ours may readily be a touch above theoretical considerations.

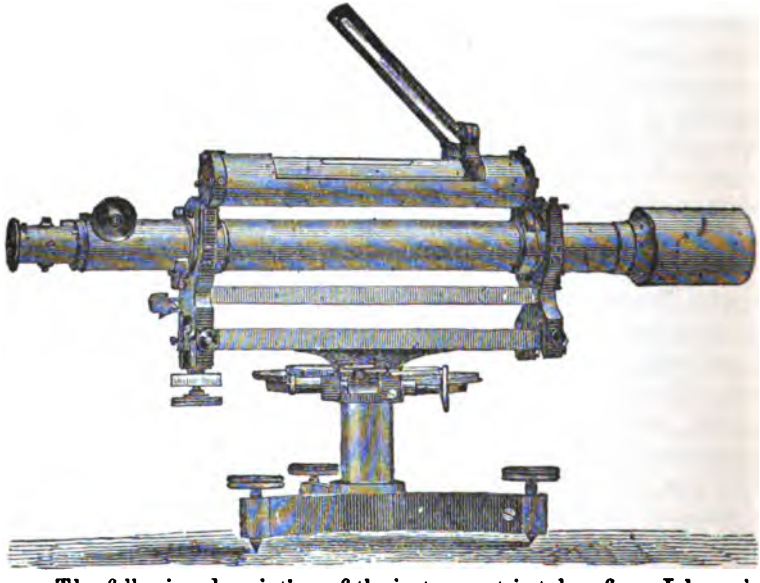
For convenience only is it desirable that the bubble should remain central while the instrument rotates about its vertical axis. In the dumpy this adjustment must be made before, and in the wye after, the essential adjustments have been completed. It is commonly stated in defence of the indirect method, that there is a saving of time as compared with the direct or "peg" method. Such is, however, not the author's experience. The time-consuming portion of the work is

the making of the necessary corrections to the level tube and reticule. In the essential adjustments by the indirect method both may require correction, whereas in the direct method only one of them—preferably the reticule—should be moved. We have then in comparing the relative convenience of the two, on the one hand the matter of setting up the instrument once and making two or three rod readings, and on the other the complete adjustment of the level tube. The writer would rather set up ten instruments and make as many rod readings (and could do it in less time), than adjust one bubble tube. This indirect method seems to him to have, for the purposes of ordinary levelling, no one point to commend it in preference to the direct method, and has the disadvantage that it does not guarantee correct adjustment, unless the pivots have, after careful examination, been ascertained to be equal; or the proper correction determined and applied. The wye is undoubtedly the most scientific instrument, and for precise work has some advantages,—such, for example, as the possibility of eliminating the error due to want of coincidence of the sliding tube with the line of sight. In a well constructed dumpy, however, this error must always be trifling. The writer has never been able to understand why the wye level should be used in ordinary levelling in preference to the dumpy. The wye form is more difficult of construction, more expensive, less rigid when constructed, and hence more liable to get out of repair. The most abominable instrument ever put in the hand of man is an old and shaky wye level. He submits that in the interest of good work, if not of economy, the construction of the wye form for ordinary levelling should be abandoned in favor of the more compact and rigid dumpy. The modification of the dumpy, such as Cushing's reversible level and other deviations from the type form, do not, for similar reasons, commend themselves to him. The adjustments for coincidence of the optical axes of the objective lens and the eye-piece with one another and with the axis of the tube, provided for in the wye but not in the dumpy, are really makers' adjustments, and except in the case in which the axis of the objective slide makes an angle with that of the tube are not essential to correct work.* A very important point to be attended to in the construction of all levels, and in the examination of them from time to time by the Engineer, is that the object lens is not loose in its cell, and that the cell is not loose in the telescope tube. Both these defects are apt to occur through time. The tightening

* The test for this error is most conveniently made in the wye by sighting on a distant and a near object in the reversed position of the telescope tube, and in the dumpy should be made by the three peg method referred to by Mr. Irwin in the discussion.

band at the back of the cell should screw into place in order to permit such a defect being rectified. An instrument having a loose objective is impossible of adjustment and fatal to good work.

The accompanying cut, taken from Fauth's catalogue, represents an instrument of the form used in geodesic work. The pattern employed by the United States Coast and Geodetic Survey differs slightly from this instrument, which is the one prescribed by the International Geodetic Commission, held in Berlin in 1864, and used in this country on the Lake and Mississippi River surveys.



The following description of the instrument is taken from Johnson's Theory and Practice of Surveying:—

"The bubble is enclosed in a wooden case (metal case in the cut), "and rests on top of the pivots or rings; it is carried in the hand "when the instrument is transported. A mirror is provided which "enables the observer to read the bubble without moving his eye from "the eye-piece. There is a thumb-screw with a very fine thread "under one wye, which is used for the final levelling of the telescope, "when pointed on the rod. There are three levelling-screws and a "circular or box level for convenience in setting. The telescope "bubble is very delicate, one division on the scale corresponding to "about three seconds of arc. The bubble-tube is chambered also, "thus allowing the length of the bubble to be adjusted to different

" temperatures. The magnifying power is about 45 diameters. " There are three horizontal wires provided, set at such a distance " apart that the wire interval is about one-hundredth of the distance " to the rod. The tripod legs are covered with white cloth to dim- " inish the disturbing effects of the sun upon them. The level itself is " always kept in the shade while at work.

" The levelling-rod is made in one piece, three metres long, of dry " pine, about four inches wide on the face, and strengthened by a " piece at the back, making a T-shaped cross-section. The rods are " self-reading, that is, they are without targets, and are graduated to " centimetres. An iron spur is provided at the bottom, which fits " into a socket in an iron foot-plate. The end of the spur should be " flat and the bottom of the socket turned out to a spherical form " convex upwards. A box-level is attached to the rod to enable the " rodman to hold it vertically, and this in turn is adjusted by " means of a plumb-line. Two handles are provided for holding the " rod, and a wooden tripod to be used in adjusting the rod-bubble. " The decimetres are marked on one side of the graduations and the " centimetres on the other; all figures are inverted since the telescope " is inverting."

In the use of such a level according to the methods of precise levelling, it is necessary to determine the instrumental constants:—

1. The angular value of one division of the level tube. This may be found in the field by sighting on a rod at a known distance, taking readings of the bubble along the whole length of the graduated part of the tube, but it is more satisfactorily determined on a solidly mounted level trier.

2. The inequality in the diameter of the telescope collars. This is found by reading the striding level on the collars in the two reversed positions, thus eliminating the error due to the unequal length of the striding level legs and obtaining the true inclination of the surface of the rings. The telescope is then reversed in its wyes and the levelling repeated. The difference in the two inclinations, divided by four, gives the angular value of the error or correction sought.* The following observations are given as an example:—

	Level readings.		
	Eye end.		Object end.
Striding Level direct	7.4		9.0
" " reversed	8.0		8.4
Means	=7.7	and	8.7
			7.7
			2)1.0
Inclination of upper surface of collars.			=0.50

* See Chauventet's Astronomy, Vol. II, p. 153.

Telescope reversed in Wyes.

	Level readings.		
	Object end.		Eye end.
Striding level reversed	5.6		11.0
" " direct	5.0		11.6
Means	=5.3	and	11.3
			5.3
			2)6.0

Inclination of upper surface of collars $=3.00$

Difference of readings $\frac{3.00-0.50}{4}=\frac{}{4}=0.625$

The value of one division of the level was $=5''$. Hence, correction in seconds of arc $= 5 \times 0.625 = 3.12$, and the eye end is the largest, requiring a negative correction to all rod readings.

3. The ratios of the portions of the rod intercepted between the three wires and the distances of the rod. This for the double purpose of obtaining a measure of the length of sights and furnishing a check on the readings.

The adjustments—making due allowance for the fact that the level tube is moveable—are the same as those for the ordinary wye. Since, however, it is impossible to do anything exactly, and in the best work the smallest errors should be provided for, the after-treatment of the adjustments is essentially different. They are reduced to as near zero as possible, and the outstanding errors determined as follows:—1. The difference in the average of the three rod readings in the two reversed positions of the telescope tube gives twice the collimation error of the mean line of sight, at the known distance of the rod. 2. The inclination of the bubble-axis to the top surface of the rings is found by taking a series of readings of the bubble in the reversed positions, the average of the mean differences at the eye end and at the object end, for level direct and level reversed, gives twice the correction required for the inclination of the level tube. Thus, in the example already given, the difference is 0.6 div. and the correction $0.3 \times 5.0 = 1.''50$.

These determinations are made at the beginning and the end of each day's work, and their resulting values combined with the correction for inequality of collars, applied, in the reduction of the notes, to all rod readings.

Methods of work. The method of using these instruments differs from ordinary work only in that there are three rod readings for each setting of the rod, and the reading employed is the mean of these. In some cases the bubble is kept central by means of the micrometer screw and the reflecting mirror; and in other cases only approximately so, the

ends being read and recorded by an assistant. A correction is, in the latter case, afterwards applied to each rod reading for the inclination of the line of sight. The three readings of the rod in each position should always be compared before the level is moved, in order, if necessary, that any doubtful reading may be checked. Self-reading rods, usually graduated to centimeters and estimated to millimeters, are employed on the Lakes and Mississippi River surveys, and in most of the European work. On the Coast and Geodetic Survey, target rods are used, and the method of work there pursued is much more elaborate than the foregoing.

The methods of levelling are sometimes described as *single* or *double* levelling, according as single or double back and fore sight are taken. The latter has been the practice of the Coast Survey, and is a self-checking system—in so far at least as the readings are concerned—really amounting to two lines of levels in the same direction. The single system is, however, the more generally adopted. There is a decided economy in time and in accuracy of result in the use of two rods alternating with one another on turning points.

In reviewing the construction of levelling instruments, the principal points to be held in mind as conducive to the best results in the various departments of work would seem to be. First,—stability of construction; second, properly constructed levels of sufficient delicacy; third, adequate optical power for the purpose in view. The first condition should be secured by a proper distribution of the metal, for the attainment of the necessary strength from a minimum of material. The second and third are to a certain extent interdependent. For railroad and canal work from 10″ to 20″ per division of 0.1″ would seem to be limiting values for the scale values of levels. Levels having a scale value of 12″ are entirely satisfactory on ordinary work, while those beyond 20″ the writer has considered as lacking in sensitiveness. It has always seemed to him better to have an over-sensitive than an under-sensitive level, admitting the difficulty of keeping the former central.

Increased optical power is of course secured at the sacrifice of light and definition. The powers demanded for our instruments are, however, much below the maximun limit for good lenses, under the ordinary conditions of illumination. Referring to the list of instruments already given, the practice of the makers of dumpy levels seems to be to keep in the neighbourhood of 25 for the higher powers for 14 in. instruments. The object lenses of all these instruments would stand higher powers. With a good object glass of 1.5 in. aperture there should be no

difficulty in using a power of 40 under the ordinary conditions of seeing. In the smaller apertures of the wye levels the matter of loss of light becomes serious. But the makers of wye levels seem altogether born to perversity,—having decided to use an object glass of small aperture, they must of necessity add to this a four lens eye-piece, as if it were any advantage to get an erect image. The four lens inverting eye-piece has no advantage over the ordinary erecting eye-piece, and its use results in serious loss of light, giving a comparatively indistinct image —one of the most fruitful sources of error in levelling.

The use of the mirror on level tubes to view the bubble is not in such favour with engineers as it should be. The usual process of reading the rod while standing in a different position from that in which the instrument was levelled must necessarily introduce errors of a serious nature. When the mirror is used it should always be placed at the same inclination, and the observer should by trial, assisted by another person, obtain that position of the eye in which the bubble may be viewed without parallax, and from which he will always afterwards observe it.

It is usual to classify sources of error somewhat as follows:— 1, instrumental errors; 2, errors from unstable supports; 3, errors of observation; 4, personal errors; 5, atmospheric errors. The chief source of error from *instrumental* causes is no doubt due to either a permanent or temporary lack of parallelism between the line of sight and the bubble-axis. No adjustment can be perfect, and even if perfect under stated conditions is liable to change under other conditions. The causes which might produce a change in adjustment due to the influence of varying temperature on the glass of the level has been discussed in the first part of this paper. A temporary change may result from the unequal heating of the metal of the instrument, which would probably take place in bright weather when levelling, in a direction towards or away from the sun. The direct action of the sun should be avoided by the use of a shade—a heavy canvas umbrella is used on geodetic work. In order to obviate the effect of any possible change in the scale value of the level, readings should never be taken when the bubble is at any considerable distance from central. If the bubble is sluggish there is a possible source of error in its being read before final settlement. This latter difficulty can be overcome, with a chambered level, by avoiding the use of short bubbles. Errors arising from defects of adjustment are of course completely eliminated by equality of sights, except in such a case as that mentioned above, where, on account of the direct heating action of the sun, a change may take

place between sights. Such changes are much more likely to affect the results of ordinary levelling where there is an interval of time between centering the bubble and reading the rod. Errors of this nature are, though small for any given sight, of serious consequence through always being in the same direction, or cumulative in character. If there be, of necessity, a difference in the lengths of sights, the possible error so introduced should be neutralized by making, on the first opportunity, a similar difference in the opposite direction. In the Indian Survey sights are made equal by chaining. Where, as for example in crossing a wide river, a long foresight is unavoidable, the method of reciprocal levelling, explained in connection with the peg adjustment, should be employed. This also eliminates the error due to curvature of the earth. Where there are two vertical wires and the rod is read anywhere between them, there may be a slight error introduced through the lack of horizontality of the wire. This should be provided for in making the adjustment by swinging the telescope, when correctly levelled, around its vertical axis, and rocking the reticule ring until the wire is observed to continuously bisect a fixed point. Where no rod level is used, as is usually the case in ordinary levelling, it is, however, more important that the vertical wire should be truly vertical; and where both cannot, in this case, be secured, the rod should always be read in the same position on the horizontal wire. Wye levels should always have a means of preventing the telescope from rotating in the wyes.

Errors due to the rod will also fall under this class, and we should first look to the accuracy of its length and uniformity of its graduation. Mr. I. W. Wright in his work on the adjustment of observations remarks that:—

"An important source of error in spirit levelling, and one very "commonly overlooked, is the change in length of the levelling rod "from variations of temperature. From experiments made by the "Prussian Land Survey, in which the rods were compared daily with "a steel standard, the following fluctuations in length were found for "four rods made of seasoned fir:—

Rod	13,	from	May	19	to	Aug.	18	0.51	mm.	per metre.
	14	"	"	20		"	15	0.46	"	" "
	9	"	"	24		Sept.	6	0.37	"	" "
	10	"	"	24		"	6	0.43	"	" "

"It is quite possible that errors from this source may largely exceed "the errors arising from the levelling itself. Each field party should

"therefore be provided with the means of making a daily comparison "of the rods used, with a standard of length. A steel metre and a "micrometer microscope mounted on a stand would be all that would "be necessary."

The maximum expansion above quoted would amount to .007 of a foot in the length of a 14 foot rod. It will be noted that the variation of temperature is not given. Experiments conducted by Prof. Van de Sande-Bakhuyzen on the staves used in the Netherlands, give results of much less magnitude then the above. He found the rate of expansion for seasoned fir rods to be 4.4 micra per metre, per degree centigrade, and that other changes amounted in all to not more than .05 mm. per metre.

For ordinary work the self-reading telescope rod is almost universally adopted, on account of its portability and convenience in use. The rods of this form, though sold as "standard" by the makers, are liable to be most inaccurate. Of the seven 14 ft. self-reading rods in use at McGill College, four are within .002 of a foot of being correct, one is .006 too short, and two are .014 too long, at 62° Fah. There are then two of these rods, and surprising as it may seem, both from the same makers—a London firm of high repute—which differ between themselves to the extent of .020 of a foot. Two 12 ft. target rods by different American makers are within .002 of the correct length. Amongst a lot of five telescope rods, recently measured in the warehouse of a dealer, one was found to be .020 too long at 14 feet and .015 too long at 17 feet. In most of the above cases the total error was roughly distributed throughout the length of the rod. In that last mentioned, and in one of the College rods, the graduation was somewhat irregular.

Where rods are properly constructed they should not be influenced to any great extent by moisture. The utmost precaution should, however, be exercised to keep them dry. In the Swiss levelling the errors due to temperature and moisture are stated as being "small, slow in action, and somewhat irregular." The reports published from time to time of extreme changes from moisture are no doubt due to improper protection. Where rods are used under proper direction they are of course subject to careful comparison with the national standard, and any errors in their lengths allowed for.

Errors arising from *unstable supports* may occur through the instrument or the rod, and are usually of a cumulative character. The instrument may settle slightly between the reading of the back and fore sights, or the converse may occur, depending upon the character of the ground.

Similarly, the turning points may settle or spring up between sights. In soft ground, settlement is likely to occur; while in stiff clay both instrument and rod—if the latter is supported on a peg driven in the ground—may spring back slightly. Pegs are preferred as turning points for soft ground, and plates having a projecting knob or spherical hole for the rod, as already explained, for hard soil or roads. The rod should never be removed from the point until all the readings have been made, and the weight of the rodman should never be allowed to rest upon it. When both instrument and rod move in the same direction the effects are additive, and the character of the soil continuing the same over a considerable stretch of country, a large error may be accumulated. To obviate such a result, Colonel Walker adopted, in India, the plan of alternating the order of observations at successive stations of the instrument, by reading the back staff first on one station and the forward staff first on the next. The error may in part at least be eliminated by levelling between bench-marks in opposite directions. Duplicate levels in opposite directions between benches or along the whole length of line should completely eliminate it. This is indeed the sovereign cure for all errors of a cumulative character.

Mr. Hirsch, one of the Directors of the Swiss precision levelling, has shown that the error due to settlement, other things being equal, is proportional to the length of line run. In ordinary levelling operation, the character of the ground affects the work in a different way, the feet of the observer compress the ground near the tripod legs, and displace the line of sight in the interval of time between levelling and reading the rod. To obviate this, Colonel Goulier has recommended that two of the legs be always placed parallel to the line of sight. The use of the mirror, already noticed, would also remove this source of error.

The largest source of *observational errors* is believed to be due to the want of careful centering or reading the bubble. Every leveller should know what rod reading is covered by a range of one division of his bubble at a given distance of, say 100 feet, in order that he may fully appreciate the effect of errors of this kind.

When the illumination of the two ends of the bubble is different, an error in centering is almost sure to follow, there being a tendency to bring the bubble too much towards the light. Error is also introduced through parallax, the bubble being viewed obliquely to its length. It has recently been urged by a German observer—Dr. Reinhertz*—that the bubbles should be viewed in profile. Clearness of the glass and distinctness of the graduations have much to do with the accuracy of

* Zeitschrift für Instrumentenkunde, Oct., 1890.

bubble readings. Errors of rod reading are more common with a target than with a speaking rod. The best check on the former is for both rodman and leveller to make independent readings. Where three wires are used, errors with self-reading rods are of very rare occurrence. The mean of the three readings is also without doubt more accurate than a single reading on a target rod. It does not by any means follow that because a target rod reads to .001 of a foot, that the reading is accurate within that limit. A difference in the illumination of the rod will also affect the relative accuracy of the readings, and a line running east and west will probably show different results, according as it is levelled in the forenoon or afternoon.

Under *personal errors* we have merely to note that each observer has his own peculiarities, which will largely affect the resulting difference of level over a great length of line. This is in fact the personal equation of the observer. To quote from the report of the Chief Engineer, U. S. A., for 1884: "These discrepancies vary with differ-"ent observers, and are not even constant for the same observer, are "nearly proportional to the distance, and seem to be independent of "the nature of the ground, the direction in which the work is done, "the season or the manner of supporting the rod." The results of some recent levels on the Mississippi survey go to show that this personal equation may be somewhat evanescent, particularly with young observers, and that every line of levels should be duplicated in opposite directions by the same observer within the shortest possible limits of time, in order to reduce the probability of change in the personal equation. With skilled observers of long practice, this habit is probably a constant from year to year.

For the effects of *atmosphere errors* we cannot do better than quote from Professor J. B. Johnson, who was for some time engaged on work in connection with the Lake survey. (Van Nostrand's Magazine for October, 1883.)

"Errors from this source may be classified as coming from:
"1, Wind; 2, Tremulousness; 3, Variable Refraction.

"1. Wind generally shakes the instrument, and makes the holding "of the rod difficult or impossible. For two seasons I have used a "tent on windy days to protect the instrument, and with great success. "Good work can be done in this way so long as the rod can be held. "We also have large square canvas umbrellas that can be set on the "ground to the windward of the instrument, and these effectually "shield them in ordinary windy weather.

"The tents used were wall-tents, 5 × 6 feet, and one 8-foot centre

"pole. A square iron frame, $3 \times 3\frac{1}{2}$ feet, sewed into the canvas near "the top, formed the lateral support there. It was held down by six or "eight steel pins, 18 inches long and $\frac{1}{2}$ inch diameter, with flat heads. "These passed through iron rings sewed into the bottom. There were "openings for the line of sight and a flap for the observer to enter and "pass out with the instrument. These tents were made to be used on "Gulf coast at a very windy season, when one half the time would have "been lost from high winds without them. The rodmen supported "their rods by sticks held in the hand and braced against the rod "at an angle, resting on the ground. Care had to be exercised that "the rods were not thereby lifted from their sockets in the foot plates.

"2. Tremulousness is caused by a difference of temperature between "air and ground, and always occurs in clear weather after the sun is "a few hours high. This causes the target, or figures on a speaking "rod, to appear to move up and down, giving rise to what is known "as 'dancing' or 'boiling.' This simply causes an uncertainty in "the reading, depending directly on the degree of unsteadiness. It "is a compensating error, and the observer must be his own judge as "to when he must stop work in order to obtain the required degree of "precision. The only remedy is to shorten the length of sight; but as "there are some errors that multiply directly with the number of sights "taken in a given distance, there is also a limit to which this remedy "may be profitably carried. I do not think it advisable to use sights "less than 100 feet if the highest accuracy is sought, and perhaps "never more than 400 feet, even when the atmosphere is perfectly "clear and steady. In clear weather not more than 3 or 4 hours a "day can be utilized for the best work.

"3. Variable refraction occurs when the sunshine suddenly comes "up or leaves the line; this happens along the edge of timber or under "the brow of a hill, as when the line rapidly emerges from or comes "into the shade from the sun's movement, or on partially cloudy days, "when the sun is alternately covered and clear. When from the first "source, it occurs about 8 a.m. and 4 p.m. It is a peculiar phenome-"non, and is more common in winter than in summer. The atmosphere "is apparently steady and the sight well taken; but upon checking it, "the reading has changed, and may be observed to change gradually or "suddenly, and sometimes to recover a part or all of its original move-"ment, when the instruments were known to be stable. I have seen "these changes of reading amount to 5 millimeters, or $\frac{1}{5}$th of an inch "in a distance of 100 meters, or 328 feet. If the atmosphere is found "to be in this condition, the work should be stopped for a while, as "this state of affairs is not likely to continue long."

Errors due to carelessness—and their name is legion—need not be discussed. We can make no provision for the acts of the rodman, who, being sent to hunt up a turning point, triumphantly brings it to you in his hand; nor yet for the leveller, who fails persistently to distinguish between a 6 and a 9.

Looking at the unavoidable errors of levelling in a more comprehensive manner, we may regard them as composed of three classes,—compensating errors, cumulative errors, and accidental errors. The first classes should be so manipulated as to eliminate themselves during the progress of the work. The second should be removed by the same observer repeating the work under as nearly as possible the same conditions, and in an opposite direction. Levels checked only in the same direction give fallacious results. The third are the legitimate errors inseparable from all observations, and are proportional to the square root of the distance. The errors of a properly conducted system of levels are usually considered to be of this character, and their precision tested accordingly.

The limit of probable error allowed in the Ft.

U. S. Coast and Geodetic Survey is..... $0.029 \sqrt{\text{Dist. in miles.}}$

Lake Survey..... $.041 \sqrt{\text{Dist. in miles.}}$

Mississippi River Commission..... $.021 \sqrt{\text{Dist. in miles.}}$

between duplicate lines.*

The following interesting table of the results of levelling in Great Britain, India and Switzerland has been compiled by Mr. Wilfrid Airy, M. Inst. C.E.

Average differences in a single mile of the results obtained by two observers, on ground of different degrees of inclination.

Character of Ground.	Switzerland.	India.	Great Britain.
	Foot.	Foot.	Foot.
Nearly level, very favourable circumstances of weather.	**.0230**	**.0142**	.0125
Slightly undulating, gradients not exceeding 1 in 100.	.0238	.0168	.0148
Gradients between 1 in 100 and 1 in 20.	.7039	**.0208**	.0183
Gradients between 1 in 20 and 1 in 10.	**.0566**	**.0350**	.0308
Gradients steeper than 1 in 20.			.0416

Note.—The quantities in bold face type are estimated from analogy afforded by Swiss levelling, as no direct data could be furnished.

*For two measurements the formula for probable error $\left(\pm .674 \sqrt{\frac{e\,(vv)}{m\,(m-)}} \right)$ reduces to $\pm \frac{v'}{2}$ where v' is the difference in the measurements.

In illustration of the high degree of accuracy attained over long lines, the following is taken from the report of the levelling operations in India for 1866, by Colonel Walker :—

Section.	Length in Miles.	Maximum Divergence of two Observers.	Terminal Divergence.
		Foot.	Foot.
Calcutta to Tilliagarhi.	242	0.20	0.15
Tilliagarhi to Patka Gerouli.	346	0.40	0.38
Agra to Patka Gerouli.	342	0.15	0.06

Some excellent results over duplicated lines have in recent years been obtained with the wye levels used in the engineering branch, U. S. Army. The methods adopted were practically those of precision levelling. As an example of these the following extract is given :—

Section.	Length in Miles.	Max. Divergence of two observers in Feet.	Terminal Divergence in Feet.
Sioux City to Fort Randal	179	.082	.060
Fort Randall to Pierre, Dak.	190	.156	.154

The best levelling has, however, undoubtedly been done in Switzerland. The field rules there adopted are as follows :—

1. The levelling to be executed by equal rights whenever possible ; the difference between the length of back and fore sights never to exceed ten metres.
2. The length of sight is as a rule to be limited as under :—
   (*a*) Upon railroads with gradients 1 in 100, to 100 metres.
   (*b*) " " " steep gradients, 50 to 100 metres.
   (*c*) " highroads in the plains, 30 to 60 metres.
   (*d*) " mountain roads, 10 to 25 metres.
3. The spirit level to be always shaded from the sun.
4. The three instrumental errors, viz : Collimation of optical axis, inequality of pivots, and bubble error, to be determined at least once each day.

5. The field work to be carried on continuously except on wet or windy days. Three kilometres at least should be the length of line levelled per day along railways and two along highways.
6. Bench marks to be made at every kilometre, and to be clearly described in the field book.

In preparing this paper the author has endeavoured to touch upon all classes of engineering levelling; naturally, however, the subject being one which bears more particularly on geodesic work, he has given greater attention to that department. In deprecation of a possible criticism to the effect that the major portion of the methods herein detailed are of no consequence to "practical" engineers, he would beg to remind any so disposed that possibly their particular line of work has not embraced the whole sphere of labours of the profession. He would also wish to express the hope that the members of the Canadian Society of Civil Engineers may, at some day not far distant, be called to do geodesic levelling within the boundaries of their own country.

DISCUSSION.

Mr. Hannaford asked if Professor McLeod, in writing the paper, intended to refer more particularly to astronomical observations or to everyday levelling in the field? Mr. Hannaford

Professor McLeod, in reply, stated that the paper referred to both astronomical and engineering levels—that where his remarks applied more particularly to one or the other class of levels, it is so stated in the body of the paper. Prof. McLeod.

Mr. Dodwell said that the discussion of a paper should of course consist of criticism and additional information on the same subject. In general, intelligent and profitable criticism should be either confirmation or refutation of the author's views from personal observation and experience. In the present case he was not in a position to add any information or particulars of a scientific character to the interesting paper they had just heard. The importance of accuracy in levels used in connection with astronomical telescopes is too obvious to need re-stating, but it had never occurred to him that the requisite degree of accuracy in their manufacture was so difficult—almost impossible—of attainment. For all purposes for which engineers use levels, such extreme accuracy was, happily for them, quite unnecessary. A scale value of 5.15 seconds represents, at a distance of 400 feet, a vertical height, or difference of reading on a levelling rod, of only .01 foot, from which it will readily be seen that, within ordinary limits the scale value of an engineer's level is an unimportant factor, and that the requisite degrees of accuracy in levels for engineering and for astronomical purposes respectively are not to be compared. He observes that among the liquids mentioned in the paper for filling level tubes, bisulphide of carbon does not occur. He would like to ask the author whether this very mobile substance is not sometimes used for this purpose? Perhaps also, when he closes the discussion, the author will give in brief detail an account of his method for determining the scale value of levels of precision. In the second part of his paper on the "Errors of Levelling," the author will no doubt give some material that will appeal more directly to engineers. Mr. Dodwell.

Mr. St. George. Mr. St. George said with regard to the errors of levelling in different temperatures, engineers and railroad men notice continually that when they adjust an instrument at a certain time in the day, especially in the winter time, if they happen to adjust that instrument near noon when the sun is high, and go out later in the afternoon, it would appear as if there was something wrong with the level around the centre. In levelling, an equalized sight should always be taken on the bubble.

Mr. Irwin. Mr. Irwin said he had never noticed a spirit level failing to reverse at any time during the same day on which it had been adjusted. He had a very good dumpy level which only required to be adjusted once in three or four years, and after it had been adjusted at an average temperature in summer, he found that in using it in very cold weather (once for instance when it was about zero, at which temperature the bubble occupied almost the entire length of the visible part of the tube) the bubble would not reverse to within two divisions on the glass, that is to say, its position of reversing would be two divisions further from the zero at one end of the tube than at the other, which amounts to an error really of only one division. On these occasions he used two spring clips sliding on the tube of the level, and moved them up to the points at which the bubble would reverse. He would like to ask Professor McLeod if in his opinion the level should not then work correctly. He had occasion to level once for three days, when the thermometer was about zero, and on checking back found his levels to close exactly; and during checking back he checked on a bench mark left on the end of the second day, and was only $\frac{1}{100}$th wrong in his check on that. This, he thought, showed that the method which he adopted for marking the position of the bubble was correct, and that any error due to the change in the position of the zero point of the graduations would be avoided.

CORRESPONDENCE.

Mr. G. N. Saegmuller (of Messrs. Fauth & Co., Washington) said as Messrs. Fauth & Co. grind levels at long intervals and generally a number at a time, they have always "well seasoned" ones on hand. He does not think that they ever sent out a level which had not been finished at least one or two years. They have probably a hundred fine levels on hand which were ground over two years ago. Each level has its record; they are tested after they are ground (the writer does not know how often during the operation), and the value is recorded on the level. When they use them they re-determine this value. They have never found a single instance where a decisive change in the curvature could be noticed. Nor is there any reason why they should change, and no rational explanation can be given. If the level were only ground on one side, then they could anticipate a change, and the level would have to become of lesser curvature or larger value. He does not think that Professor McLeod's figures bear out his deductions. In the first place the temperatures differ so widely among the different determinations, and in the second place the difference in the length of the bubble will explain *more* than the differences in the different resulting scale values. A short bubble will creep, and it requires a long time before it is really settled, while a long bubble will always move briskly and settle down quickly. Mr. Saegmuller.

Some astronomers have claimed to have found evidence of changes in levels. Several were returned to the writer as having changed their values, but in every case this was the result of bad mounting. The writer believes that a violent blow or a fall may change the curve, but he has never met with such a case. He tried several levels having a value of about 5″ for 1 div. of 2 mm. These he laid on blocks resting on the ends, and pressed them down at the middle, trying to bend them. He left them in this strained position for two weeks. At the end of this time he examined them again, and found that they had their old values. He pressed them as hard as he dared to go; one of them broke. Now, when a level rests, as it ought to, at the two ends, with scarcely any pressure on it, and when it is considered that a tube of brittle glass has great strength, the writer cannot see why it should change. He should like to have from Professor McLeod an explanation of what would cause such a change.

Prof. Rogers. Professor W. A. Rogers said that the only point, in addition to those which the author considers, which occurs to him is, that Messrs. Fauth & Co., who have a machine for grinding levels to any desired curvature, state that the machine will not give the finishing touches, which must be put on by a delicate hand movement. It is his experience that the general excellence of levels made in this way is greatly improved. The general curvature is more likely to be accurate if made by a machine movement, and the general form is not much disturbed by the hand finishing. Two of these levels have been investigated by the Naval Observatory with superb results.

Prof. Eastman. Professor Eastman (of the U. S. Naval Observatory, Washington) said that there is one difficulty with levels when the scale is *engraved on the tube* which is not mentioned in the paper. This etching or engraving of the lines is not of uniform depth, and after several years of use this cutting of the surface of the tube weakens it, and gives rise to irregular curves and utterly ruins the level. He used an excellent level for more than fifteen years, but in less than one year it changed from a first-class to a worthless instrument. An examination showed that the upper engraved side was a series of irregular curves.

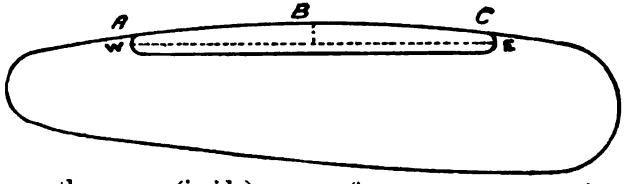
He has lately examined two level tubes for the use of the Naval Observatory, and the results are as follows:—

Values in seconds of arc of one division on level tubes.

Nos. 5 and 6 were selected from a lot of six tubes. These values were obtained by running the bubble by stages, of 5 divisions, from one end of the tube to the other, and then reversing the motion.

No. 5	No. 6
one div. = 0″.95	one div. = 0″.90
.91	.90
.92	.91
.93	.88
.94	.89
.95	.88
.93	.87
.93	.86
.94	.89
.94	.88
.94	.91
1.00	.92
1.01	.92

Mr. Chas. Carpmael (Director of the Meteorological Office) said that with nearly all of the paper he heartily agreed, but would call attention to one point, in which it seems to him that the author had not made matters clear. It is stated that "difference of sectional *area* of the ends of the tube also gives rise to a shift in the zero, *since for a given change of temperature the air space at one end will be altered in length to a greater or less extent, according as it is towards the smaller or larger end of the tube.*" The writer has underlined the part to which he refers as needing explanation. The matter would be perfectly clear if a diaphragm were inserted in the tube, preventing the flow of liquid from one end of the tube to the other, when the temperature changed; but it is not so clear at first sight why there should be any shift when the liquid is free to take up a position of equilibrium. Mr. Carpmael.



Suppose the upper (inside) curve of a central longitudinal section of the bulb be one of uniform curvature, *i.e.*, let A B C in the diagram be the arc of a circle, and further let the portions of all transverse sections (normal to A B C) which come into contact with the common surface of liquid and vapour be of one curvature, then the shape of the common surface at one end will be the same as at the other. If we take in the two ends corresponding points W and E, the total curvature of the common surface at these two points will be the same, consequently the difference of pressure between vapour and liquid will be the same and the line W E will be horizontal. Also, since the form of the surfaces is the same at both ends, W E will be equidistant from the glass surface. Also, if the perpendicular from B bisects W E, the tangent at B will be parallel to W E, and therefore horizontal. To state this result otherwise, if B be the point at which the tangent is horizontal and W E be corresponding points in the two ends, the perpendicular from B will bisect W E. No change of temperature will in this case shift the zero. If, however, the curvature of the transverse section, where it cuts the common surface, be not the same at both ends of the bubble, the shape of this common surface will not be the same at both ends. The tangent at B need not, therefore, be horizontal, nor will it in general be inclined at the same angle to the horizontal at all temperatures, as one end of the bubble will expand

towards parts of greater and the other end towards parts of less sectional curvature. In this case not only will the zero shift with differences of temperature but also (to a greater or less degree) the scale co-efficient.

Capt. De ville. Capt. E. Deville, Surveyor General, said that the results of his own experience are somewhat scattered, and he could not collect them without devoting to the subject more time than he has at his disposal. He has not been actively engaged in observing for the last eight or nine years, and his recollections are somewhat indistinct. He has been rather unfortunate in the matter of levels; of all those he has used (they are many) only one was good: it was made by Repsold. He has tried since to obtain others from the same firm, but they decline to make them except for their own instruments.

During the last two or three years the writer has ordered and received from the best makers, American and European, about one dozen of levels, and although the prices were very high, not a single one proved satisfactory. Some were plugged at the ends instead of being sealed; these it was found would invariably leak.

The mode of setting which was found most satisfactory is to let the ends of the tube rest in two brass Y's, a spring at each end pressing a piece of cork on top of the tube just above the Y. The adjustments, when made, are very steady, and there is no strain on the tube.

The conclusion the writer has come to is that a level should never be assumed to be good because it comes from a good maker; and when an observer is fortunate enough to obtain a good one, he should spare no care or pains to preserve it from accidents.

Mr. Woodward. Mr. R. S. Woodward, of U. S. Coast and Geodetic Survey, said that he could think now of only one point which it might be interesting to add to the discussion of this valuable paper, and that is that many reputable makers of instruments of precision still mount their levels very badly. Sometimes it will happen that a reasonably good level will be set in plaster of Paris. He had occasion a few years ago to exhume several good level tubes, which were set in this way by the distinguished firm of Troughton & Simms, London.

In ordering a delicate level an engineer should specify that the tube be delicately mounted. The use of V's as supports for the level tube with delicate springs to hold it in position seems the most approved way.

Professor E. A. Fuertes, of Cornell University, said that his experience with astronomical levels shows, that in addition to uniformity of curvature in a vertical plane, the internal surface of the level should be a true torus. Also, levels which at a given temperature, with a given length of bubble, seem to be uniformly graduated, will give poor division values for the same length of bubble at a different temperature. Also the manner of mounting the level in its tube has a great influence on the performance of the level. The writer would suggest the support of the level at its middle part upon a cork-lined ring, the extremities being held by cork wedges, for the purpose of steadying the level vial laterally, and placing the zeros of the graduation an inch beyond the edges of the supporting central ring. He purchased a new level (reading about 2″ per millimeter), and when he again investigated it, a year or so afterwards, its scale had changed very materially. Both trials were made on the vial, free from its mounting, and adjusted on the wyes of the level trier for the verticality of the plane containing the axis of the tube. Prof. Fuertes

Experiments are under way at Cornell University upon a plastic substance, into which the level vial may be sunk without adhering to the vial, giving the level a chance to adjust itself to temperatures, without the changes of form due to strains produced by the corresponding changes of metallic and rigid supports. A mixture of caramel syrup, glycerine and glue may produce a compound sufficiently stiff to afford a secure seat to the level, and yet allow it to expand or contract without such strains as may force an undue change of form in the glass; but the difficulty lies in the proportions of the ingredients, so as to give useful results in extremes of heat and cold. This difficulty is not considered insurmountable, however.

The most refined astronomical and geodetic observations are frequently made to depend upon the testimony given by the divisions of a level; and this testimony, the best attainable, cannot be depended upon without special investigation of the errors to which it is liable. Any effort to bring under less complex laws the inequalities of the indication of the level is worthy of encouragement, in view of the indispensable use of this instrument in many important fields of research.

Professors Chas. L. Crandall and C. B. Wing, of Cornell University, said Professor McLeod's paper shows how the zero point is affected by the length of the bubble when the tube is poor. It may not be uninteresting to determine the effect of length of bubble not due to a poor tube. With this end in view, the level tube of a geodetic level Profs. Crandall and Wing.

belonging to the University, was placed upon a level tester, and readings taken for each five seconds of arc through which the tester moved. The motion was continued through one minute of arc and back again, and the time which the bubble required to move each five seconds noted. The tube has $12\frac{1}{2}$ divisions to the inch, and each division is about 3.7 seconds.

Between the limits of 10 and 36 divisions for the length of the bubble, the time required to move over five seconds of arc is about inversely as the length, varying from about twenty seconds for the shortest to six seconds for the longest. When the bubble was less than twenty divisions long it would usually move beyond the point of rest, in which case the time required to return was as great as for the first motion; or for the short bubbles, the time required for *rest* should be doubled.

The value of a division is slightly less for the short bubble, but the more important fact is that the divisions are much more nearly equal for the long bubble. The probable error for a single reading in the length of a division with the bubble ten divisions long being 1.2 seconds, with the bubble twenty divisions long 0.6 seconds, and with the bubble thirty divisions long 0.5 seconds, showing the quality of the level to improve with the length of the bubble up to the limit taken, although the difference is slight beyond twenty divisions.

Comparing the two level readings for the same position of the tester, the bubble having come from opposite directions, the indications are that the bubble is carried beyond the true point about one-half second, the amount being slightly greater as the bubble is shorter. We say indications, because the readings were not so arranged as to eliminate instability of the tester.

Another level with about two second divisions was tested in this same manner. The bubble, when $\frac{3}{4}$ inch long, would only move for every third turn of the screw representing fifteen seconds of arc, while when lengthened to two inches the motion was uniform and the curvature apparently constant.

In conclusion, these experiments indicate that increasing the length of the bubble decreases sluggishness and increases the apparent uniformity of curvature and the accuracy of the final position of rest. This apparent uniformity of curvature may decrease if the length is carried beyond a certain limit; or it is probable that each tube will have a length of bubble for which the divisions are more nearly constant in value than for any other. This length is probably the one used by the maker in grinding and testing.

Mr. Arthur Hill said that Professor McLeod's interesting paper has afforded him at last an explanation of the probable cause of the exasperating behaviour of the bubble of a London made Dumpy level, which he has been using for the last twelve years, and which has never yet properly maintained its adjustment for twelve hours at a time. Placed in perfect adjustment in the morning it would perhaps be off at noon, and back again in the evening. Adjusted at midday, it would in all probability strike work before six o'clock. It was plain that those freaks were due to a change of temperature, but the writer never could make out *how* the change produced its annoying results. Mr. Hill.

The great advantage of having a chambered bubble tube, as described by Professor McLeod, will be appreciated by any who have experienced the difficulty referred to.

Professor McLeod, replying to the criticisms of Mr. Saegmuller, who is of opinion that no change of form can take place after the level is ground, said that there must necessarily, from the character of the manufacturing process, be internal strain in the glass of the tubes. When the skin is removed to unequal depths in the process of grinding, and relief thus given to the tensions, the whole tube will slowly take on a new figure. Even in blown glass, where there is no interference with the outer skin, it is, as has been pointed out, customary and necessary to season thermometer tubes before calibrating and graduating them. It would, even could no reason be assigned or no analogous case given, obviously be useless to maintain, in the face of the evidence given, that no change can take place. The cases cited by Professors Eastman, Fuertes and others, furnish additional and conclusive evidence in refutation of the stand taken by Mr. Saegmuller. The deduction which Mr. Saegmuller takes the speaker to task for making is, he supposes, the same change of form with age. The effect due to temperature has little or no weight in the general result, and is trifling as compared with the change through age. The constant though slight changes of form in the glass through change of temperature is probably the most efficient agency through which the greater change takes place. Prof. McLeod.

As to the effect of the length of the bubble, it will be seen that in the tests made on July 15th, 1890, the extreme limits of length of bubble employed are used, and give results which are practically identical.

It is of course well known that a long bubble will come to rest more quickly than a short one. When the length of the bubble on the level in question is half an inch long, it will come to rest in about sixty seconds; when it is one inch long, in about 35 seconds; when it is

two inches long, in about 20 seconds; and when three inches long, somewhat less than 15 seconds. Or, speaking very roughly, the length of time which the bubble takes to settle is inversely proportional to its length. A very short bubble is more searching in detecting local irregularities of curvature, and unless the level is a good one there will be a resulting lack of uniformity of scale value in the use of a short bubble. The long bubble extending to opposite ends of the tube evens up any small local errors, giving the average value of the scale value at the two ends. A level which is fairly good for a long bubble may be very poor when the bubble is short. Such was not, however, to any great extent the case with the level in question. Professor Fuertes has given an instance of this kind, and Professors Crandall and Wing have made a special investigation as to the effects of different lengths of bubbles. The average of one division along the whole length of the scale, which is the point in question with Mr. Saegmuller, is not, however, different. The speaker has this afternoon tested the level in question for a length of bubble of half an inch and for a length of 2.7 in., obtaining exactly the same average scale value for both lengths.

The length of the bubble can have and has no effect whatever on the average scale value of a perfect level. Mr. Saegmuller does not quite grasp the idea of the change of form which, the author has maintained, may take place in a properly mounted level. He seems to look to all change as being due to external strain, whereas what we are dealing with is obviously a question of internal strain.

Referring to Mr. Carl mael's remarks where the sectional area of the tube is different at the two ends, the curvature in cross section at the upper surface will, from the nature of the usual process of grinding, be different, giving the resulting change of zero referred to in the paper.

Mr. Dodwell's remarks refer more to the errors of levelling. The speaker has not been able, through lack of time, to look into carefully his suggestion to use bi-sulphide of carbon. There would be three points to consider: 1st, Its mobility. In this it probably ranks below ether; 2nd, its hygroscopic properties; and 3rd, the practical question of its use by the maker. Its highly volatile character would increase the difficulty of closing the tube. Some experiments are being made on these points, and the speaker would like to be allowed to add the results, if any are obtained, to this discussion.*

If the change in the position of the bubble referred to by Mr. Irwin

* The experiments above referred to show that bi-sulphide of carbon is somewhat more mobile than ether, and there does not seem to be any objection to its use in levels except the difficulty of manufacture.

was due to a shift of the zero, as it would seem to be, then undoubtedly the method pursued by him is the correct one, and would eliminate any error arising from that cause. It should, however, be borne in mind, that a similar result might follow from unequal contraction of the metal of the instrument, and in this case there would be an error introduced in so using the level. The golden rule is to test for each and every condition in which an instrument is used.

Professor W. Wright said he had read Professor McLeod's paper with great interest. It seems a very clear and practicable exposition, and contains many things not generally known. Prof. Wright.

One or two points might have been elaborated. For example, people should be warned against Troughton & Simms' method of placing the level tube in a metallic case and filling up with plaster of Paris. He has seen levels of this kind made by them to accompany a 14 inch theodolite for primary triangulation work. Again the very troublesome question of personal equation is touched on rather lightly.

Professor J. B. Johnson (of Washington University) said that probably Professor McLeod could have added with some profit a method of adjusting up the levels of a city plot. For instance, every city has a great many determinations of the difference of elevation between its various bench marks, and when a sufficient number of observations are obtained, it would be well (if the expense cannot be incurred of going over the whole set by *precise* methods) to try and find the most probable values of those differences. This means some system of reduction similar to that used in the writer's work on surveying, for adjusting up a network of polygons. Most city engineers do nothing of the sort, but arbitrarily fix these values. Prof. Johnson.

Neither has the author said anything on the significance of weight (or mass) in a levelling instrument. The heavier the instrument the less it is affected by wind, and a heavy instrument is always better than a light one. Most engineers seek light instruments for *comfort*, and thereby sacrifice largely in the matter of accuracy.

Mr. W. McNab said that the Society is indebted to Professor McLeod for his excellent paper on this particular branch of engineering science. The information and suggestions contained in it are of a practical nature, and cannot fail, if carefully considered, to largely assist those engaged in the work in obtaining a degree of accuracy such as perhaps may not have been aspired to before, or considered possible or necessary. Mr. McNab.

In regard to errors arising from the improper adjustments of the instruments themselves, it is noteworthy that there are, unfortunately, many levellers who obtain very incorrect results by reason of a lack of proper knowledge of the construction and principles of the level in all its details. Perhaps the most common error met with in every day work is that arising from the too frequent acceptance of the instrument as being in perfect order, provided the bubble remains stationary during a revolution of the telescope.

If those who use the instruments, but who are not well acquainted with the principles of their construction, realized for a moment the serious discrepancies that frequently result from such ignorance, it would appeal to them forcibly that the art of correct levelling consists in more than the mere mechanical reading of the staff (however accurate that may be) and bringing the bubble to the desired central point by the aid of the levelling screws.

Professor McLeod has furnished some tables showing the accuracy with which levelling has been accomplished over long distances in India and the United States; and in connection therewith it might be interesting to cite an example of what has been done in Canada in that respect. In a series of levels which were taken over the main lines of the Grand Trunk Railway in 1878, a difference of only $\frac{22}{100}$ of a foot in 220 miles was found to exist between them and levels taken in 1858, reckoning from an established bench mark in Belleville, Ont., and one in Montreal. In the former the levelling was run in a westerly and in the latter in an easterly direction between the points mentioned. Similar cases might also be quoted in respect to the result of the check levels from the railway line to the water level of Lake Ontario, at various points between Kingston and Toronto. At none of the points on the lake noted between these two cities was a difference of more than $\frac{12}{100}$ of a foot observed. The height of the normal surface of the lake had been previously determined by an arranged plan of simultaneous observations at the various points by parties detailed for the purpose; and at noon on a certain day, when the elements were perfectly calm at all the places, and had been so for at least 24 hours previously, the water level was accurately marked, and the check levels were taken from the line of the railway to these various marks.

For general use, the speaker prefers the Dumpy (but of course due allowance must be made for the makers); the adjustments may require the use of measures not necessary in the Wye, but when once thoroughly adjusted, his experience is that the former can be depended upon to preserve that condition much longer than the latter.

There is a source of error that might be mentioned in connection with levelling, and that is incorrect reading of the staff, owing to an inferior or bad style of delineation of the graduations. There are some staffs in frequent use to-day having such a confused method of graduation that they somewhat resemble a set of hieroglyphics—probably the design of some one, who, to be different from others, has sacrificed utility to originality. One style of staff which the speaker has found very simple, and the most serviceable, is graduated with a series of triangles whose angular points represent the tenths. These triangles are then subdivided into the hundredths by lines parallel with the base, the spaces being painted alternately black and white.

Professor McLeod has embraced very concisely the various sources of error connected with the instruments, and his paper, with the suggestion thrown out, cannot fail to result in benefit to those engaged in the work of levelling.

Mr. H. Irwin said Professor McLeod's paper is the more welcome since there is very little satisfactory information on the subject to be found in books. Mr. Irwin.

With regard to bubble tubes—"Gillespie," the standard American author on surveying, on page 224 of the 1883 edition, says that the bubble tube "consists of a glass tube slightly curved upwards at its middle," and on page 240 of same edition describes it as being "a curved glass tube."

In Gillespie's later book called "Higher Surveying" (a most satisfactory work), edited by Captain Cady Staley, and dated 1881, the spirit level is described on page 12 as being "a curved glass tube."

Rankine, in his edition of 1885, states that a spirit level is "a glass tube having a slight curvature, convex upwards."

Loomis, on page 44 of the edition of 1882, describes the spirit level as "a glass tube apparently cylindrical, but really a portion of a ring of very large radius."

The above is about all the information to be found on the subject of the bubble tube in the books mentioned.

Heather in his very useful book on Mathematical Instruments, edition of 1880, page 10, describes the spirit level "as a glass tube differing "from the cylindrical form by having its diameter largest in the middle "and decreasing slightly and with great regularity from the middle to "the ends;" he also gives very good criteria of a good level tube taken from Pearson's Astronomy, as well as the method of adjusting a Dumpy with three pegs, but does not explain the reason for each part of the

adjustment. Indeed the speaker has never seen any explanation of the adjustment of the cross hairs by this method in any book, and had his attention first called to that subject by his old friend and college class fellow, Mr. H. B. Hollinshead, a member of the Society.

In mentioning the correction of the cross hairs Rankine quotes Professor Blood of Queen's College, Galway, as proving that "the exact "coincidence of the cross wires with the axis of the telescope tube is not "absolutely essential to accurate levelling." See page 84 of edition of 1885. It should be noted here that he calls the line of collimation the "axis of the telescope."

Professor Blood's proof is as follows:—

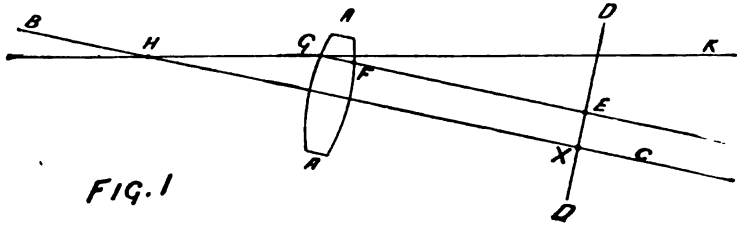


FIG. 1

"Let A A (Fig. 1) be a section of the object glass, B C the axis of "the telescope tube, and D D the diaphragm. Let E be a section of the "horizontal cross hair, not in the axis of the telescope; then when the "inner tube is drawn in and out the cross hair E will move along the "line E F, provided always that the maker has put the inner tube cor- "rectly in its proper position in regard to the outer tube so that it will "slide parallel to the outer tube.

"Let H be the *outer principal focus* of the object glass, situate on "C. B. Then, since all rays of light, whose paths within the telescope "are parallel to B C, pass through the focus H, and since, for that "reason, all possible positions of E coincide with the images of points "situate in one straight line G K; consequently G K may be regarded "as the true line of collimation, and if the spirit level be adjusted so as "to be parallel to that line correct results will be obtained in levelling, "though the cross hair be not in the axis of the telescope."

Now this proof may have seemed very satisfactory to Professor Blood, but the speaker does not believe that he ever did any very accurate levelling with a level adjusted on the above principle, and it must be noted that Professor Blood does not give his method of making the bubble tube parallel to G K.

In point of fact when an object is placed at H (the principal outer focus) no image of it can be formed at any point on the line D D; the

image would only be formed at a point infinitely distant from the object glass A A, since all the rays from H, after passing through A A, become parallel to H C, as for instance the ray F E.

Indeed an object must be placed considerably further from A A than H in order that it should be seen distinctly. The object is then at the conjugate focal distance which corresponds to the position of the cross hairs at which the object is clearly seen, and in that case, the rays of light coming from the object are no longer parallel to the line H C but converge to some point on the line D D, which point should be at X on the line B C; and the horizontal cross hair should correspond with this point.

The speaker would like to know Professor McLeod's views on the subject, Professor Blood's proof failing for the reason, that an object cannot be seen through the telescope when it is at the principal focal distance.

The correction of the cross hairs in a Dumpy level by the three peg, method, already referred to, is intimately connected with this point where Professor Blood's proof seems to the speaker to break down.

In giving the manner of correcting and adjusting a Dumpy level by the two peg method (referred to by Professor McLeod, who does not mention the three peg method), the Professor does not show how the proportion of the error due to the cross hairs being out of position and that due to the axis of the telescope not being perpendicular to the spindle, or vertical axis, can be separated.

By the three peg method, as explained in Heather's book above referred to, and which is most easily performed when the three pegs are set exactly level, by placing the instrument midway between each pair, after having adjusted the bubble so as to reverse and thereby made it at right angles to the axis of the spindle, the error due to each of the last mentioned causes can be readily ascertained. For if, after getting the three pegs exactly level (and a stout nail in the head of each will be found very convenient for accurate adjustment), the level be placed as close as possible to one of the pegs and a reading be taken on each peg, then if the error at the furthest peg be exactly double of the error at the middle peg, this error is due altogether to the axis of the telescope not being parallel to the bubble and, therefore, not at right angles to the spindle; and the error must be corrected by the screws which connect the telescope to the bar across the top of the spindle. These screws are commonly called the "body screws." But if the discrepancy at the furthest peg be either more or less than double the discrepancy at the middle peg, then this excess or deficiency in the discrepancy is due to

the cross hairs being out of position, i. e., not in the axis of collimation.

The reason why the error in reading the rod caused by the cross hairs not being in the axis of collimation is not directly proportional to the distance of the rod, seems to the speaker to be that in adjusting the focus for very distant objects, again for objects at a medium distance say of 200 feet, and finally for objects as close as can be distinctly seen through the telescope, the eyepiece and with it the cross hair is not moved out by an amount directly proportional to the distance of the object.

The result of this is that the length of rod, which can be seen in the field of view of the telescope, is not directly proportional to the distance of the rod.

For example in the case of a 16 inch Wye level, lately used by the speaker, at a distance of 400 feet can be seen 5½ feet of the rod in the field of view; at a distance of 200 feet, 3 feet of the rod, and at a distance of 12 feet, only 0.26 feet of the rod can be seen in the field of view.

Were these various lengths of rod proportional to the distances at which each length can be seen, the length of the rod which can be seen at 200 feet would be 2.72 feet instead of 3 feet.

Now these various lengths of rod which can be seen at the different distances are really the images which are formed at the diaphram; and the distance between the cross hairs, which are supposed to be out of the axis of collimation and this axis, is projected with its constant distance on these various images, and since these images are of different but not proportional lengths of rod, it follows that this constant distance, between the position of the cross hair and the axis of collimation, will cover a different length of rod at each distance which will be practically proportional to the length of rod which can be seen in the field of view; and since this latter length is not directly proportional to the distance of the rod, it follows that the error in reading, due to the cross hairs not being in the axis of collimation, will also not be directly proportional to the distance of the rod. These remarks regarding the method of discovering and correcting the error due to the cross hairs not being in the line of collimation are intended to apply to the three peg method of adjustment, which the speaker believes to be the most *direct* and satisfactory manner of adjusting a Dumpy level.

Different levels will of course not give the same difference in error at the same distance of the rod, even though the error in position of the cross hairs be the same in all.

In the case of the Wye level already referred to, the difference between the focal length for extreme distance and that for objects at 12 feet distant is only $1\frac{1}{8}$ inches.

On the other hand, the speaker found in using the Dumpy level, which has a $1\frac{7}{8}$ inch object glass of 18 inch focal length for extreme distance and a magnifying power of 40, that after reading the rod at about 500 feet it was only necessary to push out the tube about $\frac{1}{16}$ of an inch to read the rod at 250 feet, while to read it at about 10 feet away the tube had to be pushed out about $3\frac{1}{2}$ inches.

In an ordinary American Wye level the extreme length of the adjustment for focus is generally about $1\frac{1}{2}$ inches.

While adjusting the 18 inch Dumpy level already referred to, the speaker found that in correcting the cross hairs, moving them enough to make a difference of two hundredths at 500 feet made very little difference at 250 feet due to the small change in the focal length for the two distances, while there was no perceptible change in the reading of the rod at 10 feet away, which *practically*, at least, confirms the theory of the correction of the cross wires before alluded to, and seems completely to refute the argument of Professor Blood.

It might be mentioned that the level above referred to has a sensitive bubble, the scale value being about $\frac{1}{100}$ of an inch in 400 feet or 5 seconds per division.

Professor McLeod gives a "*second method*" of getting the true difference in level between two points which is new to the speaker; it reminds him of a method followed by some instrument makers in adjusting Dumpy levels. They set up a Wye level, adjust it, measure the height of the object glass above the floor, mark a point on a wall or other distant object coincident with the cross hairs, and then set a Dumpy level where the Wye level was set up, get it levelled with the centre of its object glass at the same height above the floor as the Wye level was, and then make the cross hair of the Dumpy cut the same mark as made from the Wye level.

The speaker does not altogether agree with Professor McLeod as to the time taken to correct a level by the indirect method as compared with the time required to adjust it by the direct method.

Probably in the case of a very sensitive bubble the indirect would be about as long as the direct method. The speaker's experience is that it takes a very short time to adjust the bubble of an ordinary level, and it certainly takes a much shorter time to adjust the cross hairs and the telescope axis of a Wye level than those of a Dumpy.

The speaker does not agree with Professor McLeod where he says

that in the direct method only one of the two adjustments need be made, and that adjustment should be preferably that of the reticule. He is of opinion that in the direct method three pegs should be used, and both of the above adjustments made by the means already described; at any rate the part of the error due to the cross hairs being out of the axis of collimation should be corrected by moving the cross hairs; and the part of the error due to the telescope tube being not parallel to the bubble should be corrected by adjusting the tube.

The speaker has had practical experience of the fact mentioned by Professor McLeod, that even after correcting a Wye level by the direct method, it may still be out of adjustment in the Y's.

He quite agrees with Professor McLeod as to his preference for the Dumpy over the Wye level, more especially the American make of the latter, in which the parallel plates are detached from the spindle each time the level is put into its box. This is the worst feature in a Wye level, as the screw used to clamp the spindle into place seems to throw the instrument more or less out of adjustment every time it is taken out of the box. And as for quickness of adjustment, though the speaker believes that an ordinary Wye level can be adjusted more readily by the indirect method than an ordinary Dumpy can by the three peg direct method, yet the former requires to be adjusted about ten times as often as the latter. With regard to the error sometimes due to the inner tube not sliding in the line of sight, the speaker considers the stout tubes used by American makers to be much better than the thin tubes of English made levels, since it is almost impossible to turn the thin tubes sufficiently true to ensure their fitting properly one within the other. He has been informed by an instrument maker that the best plan of turning the tubes is to leave a slightly thicker collar on the outside at the end of the inner tube furthest from the eyepiece, and a similar collar on the inside of the outer tube at the end furthest from the object glass. It would seem that in this case the inside tube would have to be put into position by taking out the object glass and putting the inner tube in at that end.

With regard to the object glass cell becoming loose in the tube, the speaker remembers some years since an occasion on which a transit man ran a flat curve in place of a straight line, through the object glass not being screwed tightly into place.

In regard to construction of levels, one point to be attended to is the length of the spindle. This is usually about two and one half inches, but with a sensitive level tube of say a scale value of about 6" per division the spindle would work better if it were an inch longer. It is also important to see that the socket of the ball and socket joint does not

work tight and bind on the end of the spindle so as to make the telescope turn round stiffly when the instrument is set up in a crooked position. The speaker has experienced trouble with a level from this cause.

The speaker fully agrees with Professor McLeod's opinion that it is better to have an over-sensitive level than one that is under-sensitive. With a very sensitive one, accurate work can be done when necessary; and when no great accuracy is required the bubble need not be levelled too carefully.

It is doubtful whether a higher power than 30 could be used with a fourteen inch telescope and a one and a half inch object glass, that is by persons of average power of sight.

The speaker's experience in using an 18 inch Dumpy with a one and seven eighths inch object glass is that a power of 40 is as high as can be used except in very clear weather. It must be remembered that any haziness or refraction due to moisture, or unequal heating of the air, renders it very difficult to see with a high power. Why erecting eyepieces are put into Wye levels the speaker cannot understand.

With regard to reciprocal levelling for transferring levels across a wide river or a ravine; if the instrument be in fair adjustment, it would seem to be as handy to get a reading on a point (A) close to the level and then one on the opposite side on a point (B), then to go over close to B and read A and B again, as to make use of the method described by Professor McLeod.

It may be of interest to explain how the error due to curvature is eliminated by reciprocal levelling.

This may be done as follows, viz:

Suppose that the height of instrument when set near A be 93.65, that the reading of the rod on A be 6.37 and on B be 5.25, this would give for the elevation of A 87.28 and for that of B 88.40; but since the level really gives the line of a tangent to the earth's surface at A, the reading at B will be too great, and therefore B will appear too low. Let this error due to curvature be 0.02 feet, then the reading at B should have been 5.23 and the elevation of B should be 88.42 instead of 88.40.

Now on going over near to B let the reading on A be 7.89, then assuming an error due to curvature of 0.02 feet and no error due to refraction, the reading on B will be 6.73 and the respective elevations of A and B will be 87.28 and 88.44; the height of instrument taken from the reading on B being 95.17. But on account of the error of 0.02 due to curvature, the second reading at A should have been 7.87 instead of 7.89, this would change the height of instrument to 95.15, and would give 87.28 and 88.42 as the elevations of A and B respectively.

In such a case the level book would read somewhat as follows, viz:

	STATION	ROD	HEIGHT OF IN.	ELEV.	
Instrument near A	A	6.37	93.65	87.28	
	B	5.25		88.40	88.40
Reading on B should be		5.23	Elevation	88.42	
Instrument near B	A	7 89	95.17	87.28	
	B	6.73		88.44	88.44
Reading on A should be		7.87	95.15	88.42	
					176.84

Mean of the two elevations of B being the correct elevation 88.42

Since the error due to refraction, though different in kind, may be eliminated by the same method if the readings be taken as quickly as possible so as to get the same refraction in both cases; or, better still, if two levels be used and the readings across the river or ravine be taken at the same time, it would seem as if it were a better method than that practised by some engineers of reading across the river and then reading the rod at the same distance along the bank of the river, and then checking this latter reading by levelling over the same distance with short sights, for in this latter case it is sometimes impossible to obtain a reading along the bank at the same distance as across the river, and besides in reading along the bank the refraction is not at all the same as in reading across a river.

Since refraction has been alluded to, and since it may cause considerable errors in levelling across wide rivers, it may be of interest to give the method of ascertaining the error due to that cause which was used by General Roy on the Trigonometrical Survey. It is as follows, viz:

In the diagram (Fig. 2), let C represent the centre of the earth, A and B the true places of two stations above the surface S S; A D and B O horizontal lines at right angles to the radii A C and B C; *a* and *b* the *apparent places* of A and B.

In the quadrilateral AEBC, the angles at A and B are right angles therefore the sum of the angles at E and C are equal to two right angles and also equal to the three angles A, E and B of the triangle A E B; taking away the angle E common to both, the angle C or the arc SS, remains equal to E A B + E B A, or in other words, *the sum of the reciprocal depressions below the horizontal lines A D and B O, repre-*

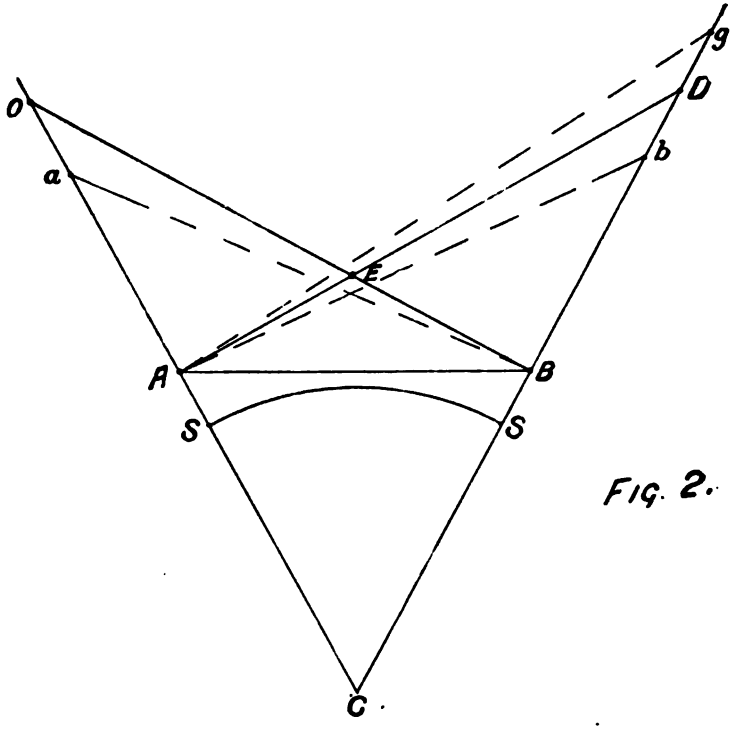


FIG. 2.

sented by the angles E A B + E B A, would be equal to the contained arc if there were no refraction. But *a* and *b* being the apparent places of the objects A and B, the observed angles of depression will be D A *b* and O B *a;* therefore their sum taken from the angle C (the contained arc of distance) will leave the angles *b* A B and *a* B A the sum of the two refractions; hence supposing half that sum to be the true refraction, we have the following rule when the objects are reciprocally depressed: *Subtract the sum of the two depressions from the contained arc, and half the remainder is the mean refraction.*

If one of the points B, instead of being depressed, be elevated suppose to the point *g*, the angle of elevation being *g* A D, then the sum of the two angles, *e* A B and *e* B A will be greater than E A B + E B A (the angle C, or the contained arc) by the angle of elevation *e* A D; but if from *e* A B + *e* B A, we take the depression O B *a*, there will remain *e* A B + *a* B A, the sum of the two refractions; the rule for the mean refraction then in this case is: *Subtract the depression from the sum of*

the contained arc and the elevation and half the remainder is the mean refraction.

The distance between the points A and B being known, the angle C can easily be found, since the mean value of the length of the arc on the earth's surface subtended by an angle of one second at the centre is 101.42 feet.

In levelling operations the angles of elevation and depression above referred to can be calculated from the observed differences of level and the distance between the points.

The error of 0.02 feet between the lengths of two 14′ levelling rods, referred to by Professor McLeod, would make no practical difference in ordinary railway work, provided the error was evenly distributed over the rod, and that the same rod were used throughout the work; except where a steep and high hill had to be levelled over, and even then in going up 240 feet, say with 20 shifts of the level, the error would only be about 5 inches, which would be spread over about three miles of pretty stiff grades.

As regards errors from not holding the rod vertically, the speaker prefers to have his rodman stand at right angles to the line of sight instead of facing the level. In this way the rodman can see if the rod be vertical in the plane of the line of sight, and the leveller can see if it be vertical in the plane square to the line of sight. Probably for accurate levelling some form of rod level which can be readily adjusted would be useful. The speaker would like to see a series of levels carried across the country under the control of the Government.

Mr. Robertson

The author's preference for the "Dumpy" level is the usual conclusion arrived at by engineers familiar with the use of both forms. Still the English tripod which is usually attached to this instrument is a decided drawback.

In Rankine's Civil Engineering it is demonstrated that the exact coincidence of the cross hairs with the axis of the telescope is not essential to accurate levelling. Still it seems that if the *direct* method of adjusting a Wye level be followed as described in this paper, there is a possibility of the cross hairs being moved far from the axis of the telescope, according to the position in which the bubble tube may be found.

The sentence referred to is: "In the essential adjustments by the indirect method, both may require correction, whereas in the direct method only one of them—preferably the reticule—need be moved."

Now, supposing some mischievous person had screwed up one end of the bubble tube, it would not be readily noticed on a Wye level, for there

are no bearing blocks. You would proceed to adjust the cross hairs as directed to bring the line of sight parallel to the bubble axis, and thereby shift the cross hairs far from the axis of the telescope.

It appears to the writer that in order to insure the cross hairs remaining approximate to the axis of the telescope, in the case of the Wye level, whether adjusting by direct or by indirect method, the cross hairs should be centred first, by revolving the telescope in its bearings, and then the bubble axis brought parallel to the line of sight; whereas with the Dumpy the bubble tube should be screwed down to the blocks at both ends, which is its most secure position, and then the line of sight brought parallel to the bubble axis by moving the cross hairs.

In comparing the direct with the indirect method of adjusting a Wye level, the author will probably have everyone with him as to the greater accuracy of the former; but as to the saving of time the writer has tried to prove that there should not be the saving of the adjustment of one set of screws, and there is also the consideration that the indirect method may be practiced under shelter from wind, sunshine, rain, and above all with warm fingers.

Professor McLeod, in reply, said that Professor Johnson's suggestion of a method of establishing the most probable values of bench marks in the system of levels of a city is an exceedingly valuable one, and will no doubt be taken advantage of by our city engineers. Prof. McLeod.

Referring to Mr. Irwin's remarks, the author does not understand how Professor Blood's demonstration has survived through the many editions of Rankine's Civil Engineering. Referring to the diagram on page 312, Professor Blood's statement, that all points on the line G H will form an image somewhere on the line F E, is perfectly correct, but this does not constitute G H the line of sight. For any given position, the line of sight will be from a point on G H through the centre of the lens to a point on F E. For any other position on G H the line of sight will also pass through the centre of the lens to a point on the line F E. There will consequently be an angle between these two lines of sight, and if the axis of the level be parallel to one of them, it cannot be parallel to the other; and hence, theoretically, no perfect condition of adjustment can exist when the cross hairs are not in the axis of the instrument. It is, however, perfectly true that the extent of the deviation from horizontality of the line of sight, on change of focus due to the non-coincidence of the line of sight with the optical axis of the instrument, is very trifling in a fairly well made instrument, and may, when the adjustments are properly made, be safely

neglected in ordinary levelling operations. In order that justice may be done the maker in this respect, the instrument should of course first be made to "traverse," or the bubble to retain approximately a central position, while the instrument is turned through 180°. But this is the very condition which we are told is unnecessary. Any one having a level and a spare hour may easily satisfy himself on this point, experimentally. Let him first, while the instrument is in its normal condition of adjustment, make readings on points at different distances; then throw the cross hairs out of position, to their extreme limit, and bring the level axis parallel to the line of sight. On repeating the readings on the same points as formerly, the different condition of adjustment will be obvious.

Intending only to touch lightly on the matter of adjustment, the author has unfortunately neglected to state specifically how this condition of adjustment may be examined in the Dumpy. One of the special advantages of the method of adjustment which he has recommended—the "reciprocal" method—is that it admits of this test being applied by afterwards setting the instrument back at a considerable distance from one of the pegs in a line with the other, and again reading the rod on the pegs. Any discrepancy discovered in the readings will be due to the lack of coincidence of the optical axis of the telescope with the line of sight, in the two positions of the draw tube. The three peg method mentioned by Mr. Irwin accomplishes the same object, but at a sacrifice of time. The author wishes to insist, however, that this is not in the ordinary sense an adjustment, and need only be applied as a test of workmanship after purchase or repairs.

The matter of length of time occupied in adjusting the different classes of instruments is entirely a question of experience. What the author has stated is his experience. The statement that the reticule only need be moved in the adjustment of the Dumpy was made for the reason that—as already stated—it is not essential for ordinary work that the bubble should remain absolutely central while the instrument is revolved about its vertical axis, and that in a good instrument the level tube usually retains its adjustment with sufficient accuracy to prevent the necessity of change. The statement in the text should, however, have been qualified in this sense. It has been already shown that the use of three pegs is unnecessary, and the author quite admits that the Wye level can be adjusted in less time than can the Dumpy by the three peg method, but he never contemplated using three pegs.

As to the uses of higher powers on levels, it need only be stated in reply that powers of 45 or over are constantly used on 1½ in. object glasses in precise levelling operations.

In this discussion we may have to some extent strained at gnats, but the author really has no intention of swallowing the large-sized camel which Mr. Irwin has laid down as an article of ordinary railroad diet—a fourteen foot rod, measuring 14.02 feet. Should a new engineer with a correct rod appear on the scene, what would an unfortunate contractor, who might be called upon to take an extra five inch cut from the bottom of a "whin" rock cutting, have to say about this matter?

Mr. Robertson, in his remarks, has also pushed the wording of the paper to an extreme of sense. No person worthy of the position of leveller could be "taken in" by the "small boy" in the way he suggests. As a matter of course any leveller would examine the level to see that the bubble remained approximately in position before adjusting, and under the ordinary conditions of use it will be found to keep this condition sufficiently well to admit of the most accurate adjustment * for all positions of focus by simply moving the cross-hairs.

* It sometimes happens that from imperfect workmanship the draw tube is not straight or of perfectly circular form throughout. In such a case perfect adjustment for all positions of focus is of course impossible.

Thursday, 20th November.

H. WALLIS, Member of Council, in the Chair.

The following, having been ballotted for, were declared duly elected as :—

MEMBER.

ELMER LAWRENCE CORTHELL.

ASSOCIATES.

ALFRED ADOLPHE DION. RICHARD WILLIAM FARLEY.

EDGAR WILKES RATHBUN.

STUDENTS.

WILLIAM NORTON CUNNINGHAM.
CHARLES BURRARD KINGSTON.
HORACE BRUCE KIPPEN.
J. MURRAY MCGREGOR.
J. GEO. RAVENHURST WAINWRIGHT.
JOHN ALDER SMART.
JAMES ALBERT STEVENSON.
JAMES TIGHE.

The following has been transferred from the class of Associate Members to that of Members :—

F. X. THOMAS BERLINGUET.

The following has been transferred from the class of Students to that of Associate Members :—

NOEL EDGELL BROOKE.

In consequence of the small attendance of members, it was unanimously resolved to postpone the reading and discussion of papers until the next meeting.

Friday, 28th November.

P. W. ST. GEORGE, Member of Council, in the Chair.

Paper No. 46.

CABLE RAILWAYS.

By P. H. MIDDLETON, Stud.Can.Soc.C.E.

Haulage by wire cables has of late years come into somewhat extended use in many different forms, and for many different purposes; but in this paper it is intended to treat only of the application of the endless cable system to the traction of street railway cars. San Francisco was the nursery from which this method of transit emanated, for, in 1873, that city boasted its first cable road in active operation, and succeeding years have seen the number steadily increasing, until, in 1888, the system had been adopted, not only in several of the large cities of the United States, but in Melbourne and Sydney, Australia, and in London, Edinburgh and Birmingham, Great Britain, while the number in San Francisco itself had increased to seven.

The advantages claimed for the cable system of street railways may be classed as follows:—

1st. The steepest grades are as easily worked as levels;

2nd. The easy manipulation of the cars, the stopping and starting being effected quickly and without shock;

3rd. Uniformity of running speed. The rate most suitable for any district and any service can be established and maintained with regularity;

4th. The capacity may be very largely increased at a very small additional cost;

5th. The cleanliness of the track and greater comfort to passengers;

6th. Low cost of management and running expenses.

With regard to gradients, the cable system of haulage reaches far beyond the capacities of any other method. Streets, where the grades are so steep that the use of horse cars is either too expensive or altogether impossible, can be served with cable cars as cheaply as on the level, thus meeting the public requirements in this direction, in localities which would otherwise never receive any such accommodation.

There are cable roads in operation in San Francisco, having grades of 1 in 6, and one in Los Angeles with a grade of 1 in 5. In the matter of curves there is no difficulty whatever, as street corners can be turned as readily with the cable as with horse cars. Lines can be crossed for serving streets at right angles to each other, by placing one conduit below the other; and switching from one line to another may also be accomplished with facility. The Market street cable road, San Francisco, is a good example of what can be done in this direction. By referring to Figure 1, Plate X, it will be seen that there are four separate cables driven from one station, and operating different streets; two of them being cross or side streets in connection with the main or Market street line from and to which the cars are switched as required. An auxiliary cable is necessary to take the cars from Valencia street round the large curve across the main cables to and from Market street. The connection between cars and cable is effected by means of a gripping device, one of the most important and, as it at first proved, one of the most difficult features of the system to work out in detail. It was considered by the early designers that a rolling grip was a necessity, hence the first grip used was constructed with that idea in view, as illustrated in Fig. 2, Plate X. This type proved very inefficient, and was abandoned for the sliding grip, Fig. 3, Plate X, which has been found not to injure the cable to any serious extent, as was formerly feared. There are many different forms of grip in use, more or less simple in detail, and having more or less gripping power, but all fairly efficient and easily worked. The absence of shock in starting, promptness in stopping, and the general ease with which the cars may be handled, are strong recommendations for the system for passenger service.

Figs. 4 and 5, Plate X, show a method in which the jaws of the grip are closed by raising the rollers RR against the inclined backs of the jaws, thus forcing them upon the cable.

Figs. 6 and 7, Plate X, show the "Vogel" grip, which is operated by short levers or toggles, thus causing the jaw BB to revolve around a centre pin and close on the cable.

Fig. 3, Plate X, gives yet another style, the cable is supported by rollers at C C, and the jaws DD are closed by rods connected with working lever.

Cable roads can be run at a very much higher rate of speed than horse cars—a common speed being 8 miles per hour, while in the suburbs, where traffic is not so great, 13 miles is sometimes adopted. The system also offers great facilities for accommodating the fluctuation of

traffic at different hours of the day, more cars being added as required without any additional cost beyond a slightly increased demand upon the coal pile.

The absence of smoke, ashes and noise attendant upon the use of locomotives, worked either by steam or compressed air, and the noise and dirt and general disagreeableness of horse cars, renders the application of the cable system to passenger traffic an extremely desirable feature in the economy of modern cities.

The cable system consists mainly of an endless wire rope, driven by a stationary engine at any convenient point on the line, placed in an underground tube, and supported at intervals upon light sheaves. Along the top side of the tube runs a narrow slot, varying, on different roads, from $\frac{5}{8}$" to $\frac{3}{4}$" in width.

The road-bed is the principal feature of the cable system, one upon which the engineer is called to expend his utmost care and ingenuity, not only in the selection of the place but also in every detail of the work. It is by far the most expensive item, costing from $80,000 to $100,000 per mile, although when in operation the running expenses amount only to 8c. or 9c. per car mile, while those of electric roads vary from 12c. to 16c. per car mile. The tubes or conduits are made of greater or less depth and size, to suit the nature of the ground and climate, as they must also act as drains to carry off such water as may find its way into them. Frames, to carry guide pulleys, are built in the tube, at about 30 to 50 feet apart, and man-holes are provided at each such place to admit of the sheaves being oiled and renewed.

The track is rigidly connected to these frames and to the slot irons, to ensure their maintaining always the same relative position. Figs. 8, 9, 10, 11, 12 and 13, Plate X, show some examples of roadways and conduits, to which reference will be made later on.

The cables used are the ordinary wire rope, generally of crucible steel, as being the most durable, and vary slightly in size from 3" to 4" circumference, according to their length and the amount of traffic expected. Some lines run as much as 5 miles of cable in one length, at speeds varying from 6 to 13 miles per hour. The life of a cable is from 9 months to 2 years. The operating machinery may be placed anywhere on the line, a matter of great importance in working the business parts of large cities, as the necessity for purchasing expensive sites is thus avoided. The driving machinery is of a very simple character, consisting in the main of a pair of horizontal engines, geared simply on to a large sheave or drum. Sometimes a pair of such sheaves are used, round which the cable passes two or more times, according to the

degree of tension required for hauling the traffic of that particular road. The grooves of these driving sheaves are liable to unequal wear, and hence a differential action is established, tending to strain the cable to breaking. To remedy this difficulty a patent sheave was invented, the "Walker" differential ring, illustrated in Fig. 14, Plate X. It will be seen that each groove is in a separate ring, which, being driven by friction, is free to move independently of its fellow, but is able to slip should the strain on the cable become excessive.

Some method of providing for the variation in length of cable, due to changes of temperature, is also necessary. Some plans for this purpose are shown in Figs 15, 16 and 17, Plate X, that one which consists of two carriages being preferable to either of the others; the smaller one to take up slack due to the temperature, while the larger one is shifted when new cables are put in.

CLAY STREET HILL CABLE RAILWAY.

The first cable railway to be built in America was the Clay street hill line, in San Francisco, California. Clay street, for a long way, runs through a densely populated part of the city, and is only 49 ft. wide from house to house. Between the sidewalks there are two lines of gas pipe, one of water pipe and a street sewer, together with a few water cisterns placed at the street corners. The power station is situated about two-thirds from the lower end of the line, which has a double track of 5197 ft. in length and a $3\frac{1}{2}$ ft. gauge. The ordinary T rail, weighing 30 lbs., is used, being placed flush with the street. The grades are very heavy on this line, the steepest being 1 in 6.15. The cable is made of crucible steel wire, six strands, and of $3\frac{1}{16}$" circumference, with a total length of 11,000 feet. Pulleys of 11" diam. are placed every 39 ft. apart along the tube, and at the termini tension sheaves 8 ft. in diam. are used. By referring to Fig. 10, Plate X, it will be seen that the frame is made of cast iron, that the slot is $\frac{3}{4}$" wide, being placed off the centre to prevent dirt and sand from falling directly upon the cable and pulley, and also to allow the grip to pass under the depression pulleys which are placed at the level crossings of intersecting streets. The cars are hauled by a dummy, to which the gripping apparatus and brakes are attached. The dummy seats 16 passengers and the cars 14, while they weigh 2100 and 2800 lbs. respectively.

The power is supplied by two engines and two boilers, one pair being held in reserve in case of break downs. The boilers are 54"

in diam. by 16 ft. long, and use on an average 3700 lbs. of coal per working day of 17½ hours.

MARKET STREET CABLE RAILWAY.

Market street cable railway is one of the most important as well as the most extensive in San Francisco. The line extends from the water front along Market street, which is one of the largest thoroughfares in the city, being 3½ miles long by 120 ft. wide.

There are two branch lines diverging from the main line, which are worked from the same engine house. Fig. 1, Plate X, shows the arrangement of station and cables.

In all there are six cables used, making a total of about 12 miles of double track of standard gauge, viz., 4′ 8½″.

Fig. 8, Plate X, shows section of the road-bed which rests upon concrete piers, measuring 10 ft. deep by 5 ft. wide by 16 in. thick, placed 9 ft. apart. The track, tube, and steel slot rails are strengthened and held rigidly in place by yokes made of old T rails and angle irons, of the shape shown in the figure, placed 3 ft. apart; and concrete is then filled in to form the tube. The cable is supported upon grooved pulleys, 15″ diam., situated at intervals of 30 ft., a manhole 12″ × 16″ being placed directly over each one. The cable measures 4″ in circumference and weighs 2½ lbs. per linear foot, while the average rate of speed is 8 miles per hour.

At the termini, turn-tables 30 ft. in diam., with two sets of tracks, which are worked by the moving cable, are provided. In all there are three engine houses on the line, the principal one having a power of 400 horses. The machinery is duplicated, there being four engines in use and four to spare. Fig. 9, Plate X, shows section of the Sulter street road-bed which is somewhat similar to that on Market street. The conduit is 2′ 6″ deep by 20″ wide.

POWELL STREET CABLE RAILWAY.

Powell street line, which is also in San Francisco, is one of the more recent roads, and boasts of two cable roads which cross each other at right angles. The total mileage is 1½ of double track and 5½ of single of 3 ft. 6 in. gauge. The line is operated from one station containing two horizontal high pressure engines of the Reynold's Corliss type of valve gear, having cylinders 22″ in diam. by 48″ stroke. Six tension reels are used of 13′ 9″ in diam., placed on an 11″ shaft, each of which is divided into two grooves. The three winding drums are a

little larger than the tension reels, which are driven by a 14 ft. spur wheel, the ratio of pinion to spur wheel being as 2 to 7. The boilers, of which there are six, are 54″ diam. by 16′ long.

CHICAGO CITY CABLE RAILWAY.

Chicago City Cable Railway Co. comprises a line 17 miles long of double track, with a 4′ 8½″ gauge. In all there are seven different cables, the longest being 27,800 ft. of 4″ circumference.

Owing to the snow and frost in that city, the tube is made much deeper, being over 4 ft., while the cable is placed about 30 in. above the bottom. The driving and angle pulleys are 12 ft. in diam. The company owns 6 engines, 4 being used to work the road, the others held in reserve.

BUTTE CITY CABLE RAILWAY.

A cable road has been built on the "Vogel" system in Butte City, Montana. The principal features of this system are the limited use of concrete and its cheapness. Figs. 11, 12 and 13, Plate X, represent sections of the road-bed.

The conduit is formed by a pair of irons 10″ deep, and in lengths of 30 ft., rivetted to a sole plate. See Fig. 6, Plate X.

Inside of this subway the cable runs, and is supported at intervals of 50 ft. upon light 8″ diam. pulleys. At these intervals a man-way is built, to enable the sheaves to be renewed and oiled. This man-way may be either made of concrete, as shown in drawings, or else of cast iron, in which case it would become part and parcel of the conduit.

The irons are braced by stays rivetted to the ties, which are placed about 3 ft. apart; and thus the track, slot irons and ties become one rigid structure. Fig. 7, Plate X, represents the "Vogel" grip, which has been described before.

The Butte City line consists of 1½ miles of double track, and passes through a short tunnel and over 2000 ft. of trestle work. The grades vary from a minimum of 3 per cent. to a maximum of 18 per cent.

BIRMINGHAM CABLE RAILWAY.

In this road the tube is made of concrete laid 19″ deep and 9½″ wide. The cast iron tube frames are placed 3′ 6″ apart, and then filled in with concrete. Pulleys of 14″ diameter, placed every 50 ft., support a steel wire cable 3½″ circumference, the tensile strength being 80 tons per sq. in., and the torsional strength 35 twists in 8″. It is composed of 6 strands of 13 wires each, laid around a hempen core, cost

£626, and lasts about 18 months. The line is worked by a pair of horizontal engines, having cylinders 20″ diam. by 40″ stroke. The driving pulley is 10′ 6″ in diam. with V grooving.

Table showing cost of construction and equipment of line:—

Track with pulley, etc., complete	$33,377
Machinery buildings, offices, chimney shafts	4,786
Engine, boilers, machinery in place	5,103
Cars and gripping machinery	4,704
Cables	1,260
Auxiliary cable gear	850
Extras and payments made to various corporations, and to city for paving	7,150
Total	$57,230

The following table has also been issued by the same company:

Horse cars per mile absorb 85.5 per cent of the gross receipts.

Steam locomotion	64.5 p.c.
Cable traction	46.5 p.c.

From the drawings accompanying this paper Plate X has been prepared.

Thursday, 4th December.

JOHN KENNEDY, Vice-President, in the Chair.

The discussion of Prof. McLeod's paper, "The Errors of Levels and Levelling, Part I," occupied the evening.

Thursday, 18th December.

K. W. BLACKWELL, Member of Council, in the Chair.

The reading of Prof. McLeod's paper, "The Errors of Levels and Levelling, Part II," occupied the evening.

OBITUARY.

SAMUEL KEEFER.—About the middle of the last century, George Kieffer, a native of Alsace, born not far from Strasbourg, on the Upper Rhine, emigrated to America, and settled at Paulinskill, near Newton, the capital of Sussex county, in the then British Province of New Jersey, now one of the United States of America. His brother Jacob went on to Pennsylvania, establishing himself near Harrisburg. Though born a Frenchman, German was his mother tongue and Lutheranism his religion. On the breaking out of the Revolution in 1776, George Kieffer espoused the cause of the House of Hanover, was mustered in the Royalist ranks, and died of army fever upon Staten Island. His son George, born in 1773, was a child at his father's death, and remained at his New Jersey home until his 18th year.

The family property, consisting of two farms and a distillery, was confiscated by the United States, and George, as the son of a "United Empire Loyalist," was offered a home in Canada by the British Government. He followed an Indian trail from New Jersey to the Niagara River, at Buffalo, and crossing over selected his home in Canada, about seven miles from the Falls of Niagara. Returning to New Jersey, he brought his mother and brother, in 1792, over the same route, by packhorses, the men marching on foot. In 1797, he married Catherine Lampman, German and Lutheran as himself, and of the five sons and four daughters of this marriage, Samuel Keefer, the subject of this notice, was the fourth son.

George Kieffer spoke German until his arrival in Canada, and here changed the spelling of his name to Keefer, to secure its proper pronunciation by his English neighbors.

Samuel Keefer was born in Thorold, county of Welland, Province of Ontario, upon the 22nd January, 1811. He was the fourth son of the late George Keefer of Thorold, who was a captain in the Canadian Militia in the war of 1812, a magistrate, merchant and mill owner, and the first president of the Welland Canal Company. That great work, commenced in 1824 and completed in 1829, was accomplished by a joint stock company, and managed as such until 1841, when, upon the union of the Provinces of Upper and Lower Canada, it was taken over by the Government. The Canal passed through his father's property, and for want of any hotel accommodation his father's house was thrown open to the engineers, and it is due to this connection that Samuel Keefer, while a lad, chose the profession of Civil Engineer. His early education was limited to that afforded by the country schools within his reach; but during the construction of the canal, Upper Canada College was founded in Toronto (then known as York), through the exertions of the Lieutenant-Governor of Upper Canada, Sir John Col-

borne, afterwards Lord Seaton. Thither, on leaving the Welland Canal, Samuel Keefer went March 21st, 1831, and remained until 1833, when, owing probably to his canal experience, he was appointed secretary to the Board of Canal Commissioners for the improvement of the River St. Lawrence. The following year, on the commencement of the construction of the Cornwall Canal, he became assistant to the chief engineer, John B. Mills, and continued in this capacity under Mr. Mills' successor, Lt.-Col. Philpot, R.E., until 1839. In that year he was appointed secretary to the Board of Works, then established for Lower Canada by Ordinance of the Special Council, and upon the subsequent union of Upper and Lower Canada (which followed the Rebellion of 1837), and the establishment of a Board of Works for the United Provinces, he was appointed engineer to that Board on 17th August, 1841. Thus, at the age of 30, he attained the highest position in his profession in his native country. That this was no sinecure may be inferred from the consideration that at that time, besides the Welland Canal just taken over, and needing reconstruction and enlargement, there existed Provincial canals upon the St. Lawrence and the Richelieu rivers—while from Gaspé to Lake Huron, a main post road, crossing numerous large rivers, to be turnpiked, planked or macadamized (as stone or wood was most available), was loudly called for.

He filled this position for 13 years, 1841-1854, having also in the 3 years, from 1846 to 1848, acted as chief engineer to the Welland Canal, where he was called by the resignation of the engineer in charge. In this period he made the first surveys in 1852 for a canal on the Canadian side of the Sault Ste. Marie, the outlet of Lake Superior, which work is only now under construction.

The works constructed under the Department during the first decade of the union of the Provinces were of the most varied character, consisting of canals, roads, bridges, "slides" (for passage of timber past rapids), harbours and lighthouses. He personally surveyed and established the line of the Beauharnois Canal, the first enlargement of the Lachine Canal, and the locks and dams at St. Anne's on the Ottawa, and St. Ours on the Richelieu and directed their construction.

In 1850, he substituted for the more costly oak framed gates previously in use, solid timber ones of pine for the St. Lawrence canals, where the locks have a width of 45 and 50 feet. The timbers of pine, like very thick plank laid broadside on top of each other, were reduced at the ends to the width of the heel and toe post, but wider elsewhere, being arched against the pressure side, giving greater strength, floatation and economy of cost, as well as greater durability.

He also constructed in this period, 1843-1844, the first suspension bridge in Canada, over the Ottawa River at the Chaudière Falls, connecting the now cities of Ottawa and Hull. A wooden bridge of 300 feet span had been erected upon this by the Royal Engineers in charge of the Rideau Canal some years previously, but had fallen soon after its erection. Samuel Keefer here had an opportunity to bring his mathematical knowledge, for which he was distinguished at college, into play. He chose the Freiburg

wire in preference to the Menai chain system, and made his plans with the very limited assistance of engineering literature then accessible to him, chiefly the *Engineer and Architect's Journal.* That it is not every engineer who can build a suspension bridge is evident from subsequent experience in Canada and in the adjoining State of New York. Two Canadian suspension bridges, one over the Desjardins Canal near Hamilton, Ontario, the other over the Montmorency River, near Quebec, were blown away or fell, in the one case with loss of life; while two American bridges, one on the Genesee River at Rochester, the other over the Niagara River at Queenston, shared the same fate. Mr. Keefer had not the advantage of his less fortunate successors in having a successful example to refer to. This bridge served its purpose for 45 years, and was replaced last year, although as serviceable as ever, by a wider steel truss one, which was called for by the increased traffic.

In 1845, he was again called upon to plan an original work, of which there was no type in existence. Timber slides for the passage of cribs with men to guide them had been in use for some years, but to regulate the necessary depth of water, which must not exceed 12 to 15 inches, stop logs of varying dimensions were put in or taken out as the river at the head of the slide rose or fell. Mr. Keefer had read in the *Civil Engineer and Architect's Journal* the account of the Bear Trap sluice in use at an early date, but long before abandoned on the Pennsylvania rivers, and adopted the principle to afford an automatic regulator, by which the gates of the Bear Trap, being set for a given feed of water, would rise or fall with the fluctuation of the stream, always feeding the same quantity. This was applied to the Government slides at Ottawa, and worked successfully for years, though not now considered necessary.

In 1853, he resigned his position under the Government for a more lucrative one upon the Grand Trunk Railway, and located the line between Montreal and Kingston, which he had previously surveyed for the Government while in their service. He also conducted the hydrographic survey of the site of the Victoria Bridge, fixed the line upon which it was constructed and projected the high level bridges for this railway over the Ottawa at St. Anne's, and over the Rideau Canal near Kingston. During this period, 1853-1857, he was also supervising engineer of the Brockville & Ottawa Railway, a line which connects the St. Lawrence at Brockville with the Ottawa River, about 40 miles above the city of Ottawa.

In 1857, he re-entered the Government service, as inspector of railways and deputy commissioner of Public Works, and for seven years made a personal inspection of all the provincial railways. As deputy commissioner of Public Works, he was charged, owing to the absence of the chief commissioner, with the selection of the competition plans for the public buildings at Ottawa. His report on these plans was approved by His Excellency in Council in 1859, and the works forthwith commenced under his direction, and were so far advanced that the corner stone was laid by the Prince of Wales in 1860. The arrangement of the detached blocks, forming the Parliament buildings and departmental offices, upon three sides of a

square, is due to him, and no little of the effect of this splendid pile upon a magnificent site is due to this disposition.

He retired from the public service in 1864 to his home in Brockville, but not from the practice of his profession. In addition to the management of his private affairs, he undertook, in 1869, the construction of a wire suspension bridge at Niagara Falls, of a span of 1,268 feet, then the longest in existence, a detailed account of which appeared in *Engineering* in that year. For the plan and details of this work, he was awarded the gold medal at the Paris Exhibition of 1878. This bridge stood for nearly twenty years without failure of any kind. In 1889, the owners, without consulting Mr. Keefer, replaced the single track roadway by a double track one, and three months after this new roadway was torn from its cables and guys by a terrific wind, which registered at Buffalo, 18 miles distant, 88 m. per hour.

In 1870, he was appointed by the Government secretary to the Canal Commission, of which Sir Hugh Allan was chairman. The object of this commission of mercantile men was to determine the scale of navigation for the enlargement of the Canadian canals. In 1872, he made a survey, plans and estimates of the Baie Verte Canal, a route to connect the Gulf of St. Lawrence and the Bay of Fundy, a project which had been proposed early in the century, but which has now been abandoned in favour of a ship railway over the same route. Col. Sir Casimir Gzowski, K.G.C.M., was associated with him in this work, which was completed in 1873.

In 1875, he built the Dufferin bridge—cast iron arch—over the Rideau Canal in the city of Ottawa, and widened another, a stone arch built by the Royal Engineers over the same canal, about 50 years before.

In 1880, he was appointed one of the members of a Royal Commission, to enquire into the conduct and prosecution of the Canadian Pacific Railway from its inception to date. Up to this date this railway had been carried on as a public work. A reform Government had been in power from 1873 to 1878, and had given way to a Conservative one, which was now investigating the work of their predecessors. Samuel Keefer was a pronounced Conservative, hence the absence of his name in Government connection between 1873 and 1880.

No mention is made of what, especially since his retirement from the public service, was an important and lucrative branch of his private practice. As a competent and experienced hydraulic, bridge and railway engineer, his services as an expert and arbitrator were ever in request. His active participation in these duties continued until 1888, when his final illness began. From his experience on the Welland Canal, as a lad, to his cessation from labour, deducting his college years, he must be credited with about 60 years of practice, a long, useful and honourable career, which has in no small degree contributed to the position which Canada holds as the possessor of public works unsurpassed by any country of similar wealth and population.

He became a member of the American Society of Civil Engineers in January, 1869, and of the Institution of Civil Engineers in March, 1870. The year before his death, he was President of the Canadian Society of Civil Engineers.

In person he was about the middle height, stoutly built without corpulence. In disposition he was remarkably cheerful, with an entire freedom from any thing approaching irritability. A consistent member of the Church of England, which he represented as a lay delegate, both in the Diocesan and Provincial Synods and upon the Mission Board, his creed was, "Fear God, honour the King,—meddle not with them who are given to change."

Mr. Keefer died at his home in Brockville (from effects of malarial fever contracted nearly two years before in Toronto), on the 9th of January, 1890, within a fortnight of entering upon his eightieth year.

JOHN PAGE.—Chief Engineer of the Dominion Canals. This very able and distinguished engineer was born in Scotland, in the year 1815. He served under the late Robert Stephenson, as junior engineer of the Northern Light House Board, for a few years, until 1838, when he left for the United States, where he was employed on the Erie Canal as a stone-cutter, and afterwards as one of the sub-engineers, for about four years. In 1842 be obtained employment as draughtsman and as one of the assistant engineers on the Welland Canal, the first enlargement of which had been commenced the previous year. In September, 1842, he rose to the position of assistant to the chief engineer, and in 1846 to that of consulting engineer, on this work.

From 1850 to 1851, he located and began the construction of the Junction Canal, uniting the Galops and Point Iroquois links of the Williamsburgh Canals, of which he was then the resident engineer, and until he was appointed superintending engineer of the canals east of Kingston in 1852, in which capacity he acted until the 31st of October, 1853, when he became chief engineer of the public works department of Upper and Lower Canada, upon the retirement of the late Samuel Keefer who had filled that position since 17th August, 1841.

Mr. Page was appointed deputy commissioner of the department, 8th March, 1864, but resigned this position, and was re-appointed chief engineer on the 15th of the same month. When confederation took place, 1st July, 1867, he was nominated chief engineer of the Federal Government, on all works excepting railways, and acted in this capacity until October, 1879, when the Department of Public Works was divided into two departments, that of Railways and Canals, and the other of Public Works, comprising buildings, harbours and river improvements, etc. He was then appointed chief engineer of the canal branch.

In 1889, Mr. Page accepted nomination as President of the Canadian Society of Civil Engineers, for the following year, but he afterwards found himself compelled to withdraw his consent on account of his official duties. During the spring of 1890, he was appointed member of a Royal Commission, to examine and report on the Montreal Harbour improvements proposed by the Montreal Flood Commission of 1886-87, and by other parties.

He died suddenly in his office, at Ottawa, on the 2nd of July, 1890.

The principal works designed by or executed under Mr. Page were:—the

Junction Canal, 1851-52; the dioptric and catadioptric Light Houses at Belle-Ile, Amour Point, Cape Rosier, Bird Rock and Anticosti, along the Gulf of St. Lawrence, and the first-class Light Houses on Lakes Erie and Huron, 1858-67; the Culbute locks and dam for vessels drawing 6 feet at the lowest water on the Upper Ottawa, 1873-76; the last enlargement of the Welland canal, from a depth of 10½ to 14 feet of water on the lock sills, 1873-87; the enlargement of the River Ottawa canals at Ste. Anne, Carillon and Grenville, from 6 to 9 feet depth of water on the lock sills, 1871-83; the Lachine Canal enlargement, from 9 to 14 feet depth on the lock sills, 1873-84; the Galops, Rapide-Plat, Farran's Point and Cornwall canals, the enlargement of which, to a navigable depth of 14 feet, was commenced in 1875, and is still in progress; the Murray canal, at Presqu'île, Lake Ontario, commenced in 1882 and completed in 1889; the Tay Canal branch of the Rideau Canal, enlarged and reconstructed, 1883-89; the Sault-Ste-Marie Canal, the navigable draft of which is to be 18 feet, commenced in 1888, and now in progress; the River Trent new canals at Buckhorn and Burleigh Rapids, and at Fenelon Falls, with 5 feet water on the lock sills, 1882-88.

Apart from the construction of the works enumerated above, Mr. Page submitted many valuable reports in connection with other important and projected works, and acted as arbitrator in several complicated cases, always giving satisfaction to the Government and the contractors, who relied on the soundness of his judgment, on his great experience, and on his integrity.

By his death and that of the late Samuel Keefer, his predecessor, Canada has deen deprived of the services of two of its most experienced and skilful engineers. The canal works executed under their directions are second to none on the continents of America and Europe, as regards magnitude, stability and cost.

Mr. Page was elected a member of the Society on the 12th of May, 1887.

THOMAS TIMMIS VERNON SMITH was born on the 6th August, 1824, at Duckmanton Lodge, near Chesterfield, Derbyshire, at that time the residence of his father, whose family has been settled in Sheffield for many generations, being almost certainly the oldest in England connected with the Iron and Steel trades. Vernon Smith's father was, like his forefathers, an iron and coal master; his grandfather, who was master cutler in 1797, was himself the grandson of John Smith, who was master cutler in 1722. This last was great-grandson of Henry Smith, whose name was included in the Royal Charter granted by James I., in 1612, founding the cutlers company. The glory of this still existing company has faded during the past decades, and its position with regard to the Iron and Steel trade of England is now more or less taken by the Iron and Steel Institute, of which Vernon Smith's eldest brother was one of the founders, and has been president, thus making seven generations, from father to son, associated with the manufacture of iron and steel. On the American continent it may be of interest to mention that Vernon Smith's mother was great-grand-niece of Admiral Edward Vernon, after whom George Washington's elder half-brother who

served in the fleet commanded by that Admiral, named his Virginian home Mount Vernon, which has become a place of interest and of pilgrimage without a rival in the States.

Vernon Smith, as a very small boy, was present with his father at the opening of the Liverpool & Manchester Railway,—the pioneer railway of England. He was educated at Mill Hill Grammar School; and afterwards served a five years' apprenticeship at Newcastle-on-Tyne, with his father's friends, George and Robert Stephenson. At the end of this period he returned home to assist his father at the Stanton Iron Works, near Derby, where he remained until he became locomotive superintendent of the Southampton division of the London & South Western Railway. It was during this time that an accident happened in a tunnel to the Queen's train, on which occasion Mr. Smith rendered valuable service in relieving Her Majesty from a most dangerous situation.

In 1852, Vernon Smith was appointed manager of the Woodstock Iron Works in New Brunswick, owned by Sanderson & Co., of Sheffield. At the stoppage of those works he went to England, remaining, however, but a short time, and returned to Canada, in 1855, to superintend the construction of the Cobourg & Peterborough Railway.

In 1857, he was appointed provincial engineer under the New Brunswick Board of Trade, which position he held for several years. During this period he invented and patented a fog whistle, which has since been adopted not only in Canada, but on the English coasts and elsewhere. The original whistle bearing his name is still in use at Partridge Island, in St. John harbour.

In 1861, he returned to England, and during the next four years he visited and made special reports on various railway and mining enterprises, both in England and on the continent; and until the project was abandoned, superintended, on behalf of Overend, Gurney & Co., the construction of the Barcelona & Cette Railway.

In 1866, Vernon Smith returned to Canada and remained identified with the Dominion until his death. He went to Nova Scotia as engineer for Punchard & Clarke, the contractors for the Windsor & Annapolis Railway; and when the line was completed, he was appointed general manager. He resigned this appointment to become chief engineer to the Western Counties Railway, and spent four years over the surveys and construction of that road.

In 1877, Vernon Smith conducted a survey connecting the Intercolonial Railway with Whitehaven, N.S., which had been proposed as the winter terminus of the English mail steamers. In 1878, he went to Toronto to superintend work in connection with the Credit Valley Railway, and remained in that city for five years. During this period he wrote many articles in the press on professional subjects; amongst these a long series in *Engineering* (of London, England), on "Canadian Railways," attracted much attention, as well as a popular article in the *Nineteenth Century*, on the "Wheatfields of North America."

In 1883, a move was made to Ottawa, as a more convenient centre, and

Vernon Smith was engaged on special engineering work for the Mattawamkeag Short Line, the Gatineau Valley Railway, and other minor enterprises. In 1886, he crossed the continent on the Canadian Pacific, and prepared for the present president of that line a very exhaustive report of the railway, and the immense facilities which it afforded in opening up the interior of the country.

In 1889, Mr. Schreiber, chief engineer of Government railways, entrusted Mr. Smith with the superintendence of the survey of the proposed Harvey-Salisbury Short Line in New Brunswick. After the close of the field work of this survey, and while preparing the necessary plans and estimates for his report, Vernon Smith was attacked by "La Grippe," and after a few days illness, leaving his latest work almost completed, he died on the 15th January, 1890, in the 66th year of his age.

Mr. Smith was elected a member of the Society on the 17th of September, 1887.

EDWARD WASELL was born on the 7th of January, 1841, at Southampton, England, and died 21st April, 1890, in London, Ontario. The earliest record of him is in Canada in the year 1868, from which time until 1873 he was employed on the Great Western Railway as assistant engineer, and afterwards as chief engineer of the London, Huron & Bruce Railway, resigning in December, 1874. From 1874 to 1879 he was chief engineer of construction on the Western Counties Railway of Nova Scotia, and he also constructed the Yarmouth Water Works, Nova Scotia. From 1883 to 1885 he designed and built the sewerage system of Winnipeg, Manitoba, and was subsequently engaged in private engineering practice in Ontario.

Mr. Wasell was elected a member of the Society on the 11th October, 1888.

(Abstracts of Papers in Foreign Transactions and Periodicals.)

THE HAWKESBURY BRIDGE, NEW SOUTH WALES.

By CHARLES ORMSBY BURGE, M. Inst. C.E.

(Minutes of Proceedings of the Institution of Civil Engineers, Vol. CI., 1890.)

The author was in charge of the work for the Colonial Government, under Mr. John Whitton, engineer in chief for railways. The Colonial Government invited designs and tenders for construction, making the competition world-wide. That of the Union Bridge Company of New York was accepted.

The accepted design consisted of seven spans of 416 feet each, centre to centre of piers. The bridge is for a double track, the trusses are 28 feet apart, centre to centre. The material is of steel with eye bar tension rods and steel pins. The main girders of each span are 410 feet in length centre to centre of end pins, and 58 feet deep at centre.

The foundations are of concrete encased in steel caissons, upon which is built stone masonry. The boring showed a bed of mud and other material for a depth at maximum of 93 feet below the bed of the river. The greatest depth of water was 77 feet, range of tide 7 feet. Pier number six is the deepest, being 162 feet below water, or 50 feet of water and 112 feet of mud, etc., and being, "as far as the author is aware, the deepest bridge foundation yet sunk." The caissons for the piers are 48 feet long by 20 feet wide, with rounded or semi-circular ends, the lowest, 20 feet, is tapered outwards to 2 feet wider, making the bottom of the caissons 24 feet wide. The caissons have three dredging wells each 8 feet diameter, placed 14 feet apart centre to centre lengthwise, the spaces between the wells being 6 feet and similarly between them and the edges of the caissons. This method formed four cutting edges in longitudinal sections and two in cross section of the wells. The spaces between the wells are filled with concrete. The caissons were floated into position, and built up as their sinking progressed by dredging out the wells. The margin for lateral divergence allowed (in sinking) by the specification was 2 feet.

No. 5 caisson was the first started and proved to be the last completed. Its career was erratic. It was commenced on the 9th December, 1886,

and was only ready for masonry on the 9th October, 1888. Shortly after entering the mud its tendency was to work eastward, or at right angles to the line of the bridge. Remedies by dredging, pile-driving and anchoring were resorted to, but all failed to secure the getting it into proper position. Finally, when the caisson "was well in the sand," at 144 feet below high water (being then in 67 feet of mud, etc.), it was proposed to sink an additional caisson at its west end. This failed, and the addition was in the way and could not be removed, so there was "no alternative left but to commence the masonry at the west end "at as low a level as possible, viz., 12½ feet under the original masonry "level, and to corbel out. With the aid of a coffer dam this "corbelling was carefully carried out with solid stones 7 to 8 feet in "length, with a 9 inch overhang in each course, and though adopted "as a last resource, the centre of the column of masonry above, coin-"ciding with the centre of the west girder, is well within the base of "the original caisson; and the resultant line of the pressures of "the pier and load passes very closely to the centre of the bottom "foundation area." The author attributes nearly all the difficulties of sinking to the outward splay of the caisson at the bottom, and recommends straight sides.

No. 6 pier also behaved stubbornly. Its tendency was northward (in the line of the bridge), following a declivity in the bottom of the river, and all the remedies applied did not effect the desired object, so that the span of the girders had to be changed to suit the waywardness of this pier. The maximum pressure on the bottom of No. 6 caisson (which is the heaviest) is about 9 tons per square foot.

The erection of the superstructure was by floating an entire span into position. The bridge is in an exposed situation, and beset with tidal currents. A pontoon, 335 feet in length by 61 feet wide, and having 44 water-tight compartments, was scuttled on a gridiron at Dangar Island. This pontoon had erected upon it staging high enough to float the bridge into position (its clearance being 40 feet above high water). In this position (on the gridiron) a full span was built, and when wind and tide favoured, the pontoon was floated (by closing the chamber valves at low water). The whole was then hauled to the bridge site, ¾ of a mile away, by means of 6 inch hawsers extending from the island to the bridge, all worked by steam. This method was assisted by tugs and the flowing tide, Dangar Island being below the bridge. The span being moved in position, but higher than the piers, the lowering into position was done by the ebb tide, or when necessary by partial scuttling of the pontoon. This method was not all plain

sailing, there were many difficulties of wind and tide to battle with, and more than one span narrowly escaped wrecking. No. 6 parted its hawser during a squall. "The pontoon swung around into a dangerous position, from which it appeared impossible to avoid a collision with the structure already fixed." Dexterously, however, a successful movement was made, saving the span but reversing it end for end, making no difference, as the girders were symmetrical.

Mr. Thomas Curtis Clarke and Mr. Theodore Cooper of New York designed the structure. The Union Bridge Company sublet the work, the bridge superstructure being built by Messrs. Arrol of Glasgow, the caissons by Messrs. Head & Wrightson, the masonry by Mr. Samuelson of New South Wales. Messrs. Anderson & Barr of Jersey City, N.J., sank the piers, and Messrs. Ryland & Morse of Chicago erected the superstructure. The tender was for the bulk sum of £327,000 stg.; time allowed 2½ years.

Mr. Thos. C. Clarke gives the quantities as follows :—

	Estimated	As in work.
Tons of steel in girders.....	6,200	6,320
" " caisson	1,600	1,668
Cubic yards of concrete.....	27,600	26,593
Masonry.	4,900	5,630
(Excess masonry due to change of plan.)		
Time.....	30 months	34 months.

The bridge was opened for traffic on the 1st May, 1889, by His Excellency Lord Carrington, Governor of the Colony.

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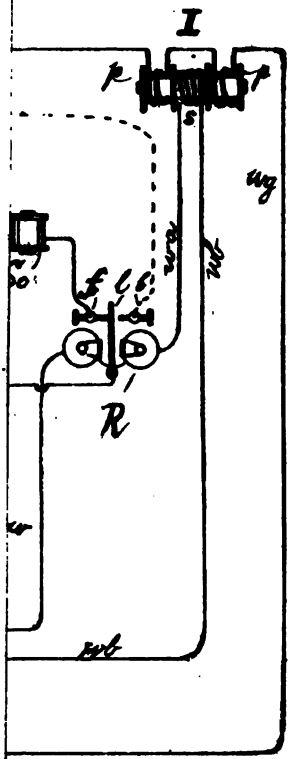

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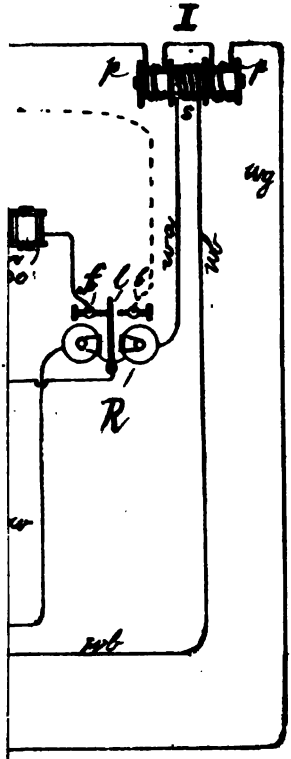
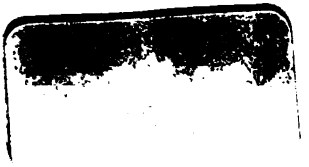
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